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ABSTRACT

The purposes of this conference are: to define the current state of technology; to identify the problems, needs and emerging technology; and to consider alternative computer applications to multiple-facility medical information systems for the delivery of medical care and for health services research. The papers presented include: (1) General Requirements for a Medical Information System (MIS); (2) Evaluation Techniques for Medical Information Systems; (3) Evaluation of a Medical Data System; (4) Quality of Data in the Medical Record; (5) Terminology and Content of the Medical Record; (6) Large vs Small, Single vs Multiple Computers; (7) A Statewide Medical Information System; (8) The Kaiser-Permanente Medical Information System; (9) High Level Programming Languages; (10) Acquisition and Analysis of Narrative Medical Record Data; (11) Visual Display Terminals in a Hospital Information System (HIS); (12) Computers and Doctors; Use and Consequences; (13) Moss Random Storage Devices and Their Application to a Medical Information System (MIS); (14) Prototype for Future Computer Medical Records and (15) The Medical Information System (MIS) for 1975. (MM)

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CONFERENCE SERIES

MEDICAL INFORMATION SYSTEMS

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Proceedings of a Conference on MEDICAL INFORMATION SYSTEMS

Morris F. Collen, M.D., Chairman

Sponsored by

THE HEALTH SERVICES RESEARCH CENTER
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- Conceptual Issues in the Analysis of Medical Care Utilization Behavior. Health Services Research Center, Kaiser Foundation Hospitals, Portland, Oregon, Dr. Merwyn Greenlick, Director

- Conference on Medical Information Systems. Health Services Research Center, Kaiser Foundation Hospitals, Oakland, California. Dr. Morris Collen, Director

- Conference on University Medical Care Programs. Health Services Research Center, Harvard Medical School, Boston, Massachusetts. Dr. P. M. Densen, Director

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PROGRAM

of a Conference on

MEDICAL INFORMATION SYSTEMS

I. REQUIREMENTS, OBJECTIVES, AND EVALUATION OF A MEDICAL INFORMATION SYSTEM (MIS)

Chairman: Morris F. Collen, B.E.E., M.D.
Director, Department of Medical Methods Research,
The Permanente Medical Group
and Kaiser Foundation Research Institute

Requirements and Objectives

Morris F. Collen, B.E.E., M.D.

Methods of Evaluation

Charles D. Flagle, D. Eng.
Professor of Operations Research,
The Johns Hopkins University

Baseline Evaluation of MIS

Robert H. Richart, Ph. D.
Senior Health Services Analyst,
Department of Medical Methods Research,
The Permanente Medical Group
and Kaiser Foundation Research Institute

II. THE CONTENT OF THE PATIENT RECORD TO BE INCLUDED IN A MEDICAL INFORMATION SYSTEM

Chairman: David D. Rutstein, M.D.
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Harvard Medical School

Quality of Data in the Record

Alvan R. Feinstein, M.D.
Professor of Medicine and Epidemiology,
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Terminology and Content of the Record

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High Density Data for MIS Records

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Professor and Chairman,
Department of Biophysics and Bioengineering,
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A Statewide MIS

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The Kaiser-Permanente MIS

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Prototype for Future Computer Medical Records

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The Medical Information System (MIS) of 1975

Bruce D. Waxman, Ph. D.
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Research and Development

FOREWORD

In December, 1968, the National Center for Health Services Research and Development granted an award to the Kaiser Foundation Research Institute to establish a Health Services Research Center. The objective of this Center is to conduct health services research within the Kaiser-Permanente medical care program, utilizing a medical information system which will ultimately provide a base of medical data for one million people.

With the encouragement and support of the National Center for Health Services Research and Development, this conference on Medical Information Systems was planned and conducted. The purposes of this conference were: to define the current state of technology; to identify the problems, needs and emerging technology; and to consider alternative computer applications to multiple-facility medical information systems for the delivery of medical care and for health services research.

These proceedings of the conference do not contain the papers of Drs. Pratt, Sweeney, and Warner because their final manuscripts were not yet available at press time. Dr. Hayes substituted for Dr. Waxman as the final speaker.

The National Center for Health Services Research and Development and the journal, *Computers and Biomedical Research,* have agreed to simultaneous publication of these conference papers.

I wish to acknowledge the enormous assistance of Ruth Straus in capably editing the final manuscripts for publication. Irene Mahoney and Esther Manuel were responsible for the final transcriptions of the manuscripts. P. H. Kidd was of great help in handling all the logistic details of the meeting. I especially wish to thank Dr. Paul Sanazaro and Dr. Robert Huntley of the National Center for Health Services and Research, and Dr. Cecil C. Cutting and Dr. Clifford H. Keene of the Kaiser-Permanente medical care program, for their personal guidance and support of this conference.

Morris F. Collen
Chairman

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GENERAL REQUIREMENTS FOR A MEDICAL INFORMATION SYSTEM (MIS)

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INTRODUCTION

The data handling and communication system of a medical facility is as essential to the success of its operation as is the nervous system to a human being. Studies in several hospitals have shown that approximately one fourth of total hospital costs are related to information handling.[1] Richart's analyses[2] of two acute general hospitals showed that 35-39 percent of the hospitals' cost per patient day were for patient-related communications. The importance of reviewing all components of health service systems in order to better use technology has been stressed by Rutstein.[3] There is an increasingly urgent need to use modern technology for a more efficient hospital information system. A significant change in data flow and communication within a hospital will have important effects on every hospital subsystem, procedure, and person.

The implementation of a computerized information communications system for other than administrative areas of hospital care has proved to be a very difficult process.[4] The reasons for this are the extraordinary requirements for long-term commitments of substantial amounts of money and for large numbers of scarce medical and engineering technical specialists, in addition to stringent requirements for size, speed, and reliability of hardware, and the difficulties in defining and standardizing the medical care process.

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Presented at a conference on Medical Information Systems, Kaiser-Permanente Health Services Research Center, San Francisco, January 28-30, 1970.

It is therefore essential to define carefully our objectives for and requirements of such a fundamentally important system.

DEFINITIONS

A medical information system (MIS), as herein defined, is one that utilizes electronic data processing and communications equipment to provide on-line processing with real time responses for patient data within one or more general medical centers, including both hospital and outpatient services.

A hospital information system (HIS) is a subcomponent of MIS that handles the inpatient medical data, including inpatient laboratory, x-ray, electrocardiography reports, etc.

A laboratory data system is a subcomponent of MIS that handles the clinical laboratory data for inpatient and outpatient services and may include input/output terminals at nurses' stations, emergency room, etc.

A hospital administrative information system is a subcomponent of MIS that handles the administrative and business functions including admission procedures, bed census, menu planning, and patient schedules for department services such as x-ray, surgery, etc.

IMMEDIATE OBJECTIVES OF MIS

The usual objectives of an MIS are to:

a. Communicate patient data from the professionals providing medical care (doctors, nurses, technicians, etc.) into the patient's computer medical record and to other professionals (e.g., dietician), and to hospital services (e.g., radiology).

b. On demand or on schedule, communicate information from the patient's computer medical record to professionals and hospital services.

c. Establish files and communicate information for scheduling of patients, personnel, and medical care services. Communicate between services, e.g., nurses' stations to radiology and dietary.

d. Establish a medical data base that has a high utility for medical services for the individual patient and physician.

e. Establish a medical data base that can fulfill research objectives for clinical, epidemiological, and health services research.

f. Establish a data base for business and administrative functions, including projection of needs and planning for services.

g. Improve the cost and quality of medical services.

h. Have capacity for (1) an increasing number of patients and of doctors (our own goal is an MIS for one million people and 1000 doctors), and (2) progressive expansion of the health service system subcomponents (for example, clinical laboratory test data are said to be doubling in volume every five years).

Since MIS will have a significant impact upon almost every person and procedure in a hospital, it becomes an important objective to evaluate the effect of MIS upon the hospital services and costs. The criteria for evaluation of MIS have been reported by Flagle.[5]

GENERAL FUNCTIONAL REQUIREMENTS OF MIS

To achieve the above objectives, MIS must be capable of fulfilling all of the following requirements:

a. For each patient, on a continuous 24 hour-day basis, capture at source, on-line if necessary, for all inpatient and outpatient services, and store in the patient computer record, the following essential information:[6] (1) Selected history, physical examination, and progress record data which are quantitated, or susceptible of some standardization of terminology and formating of input; but the system must be capable of handling natural language as necessary, (2) all diagnoses, (3) all diagnostic interpretations from x-ray, ECG, EEG, pathology and other physician-reported examinations, (4) doctors' orders, (5) all procedures, including operations, deliveries, etc., (6) all clinical laboratory test results, (7) summarized essential patient monitoring data from intensive care areas, (8) all drugs administered in the hospital and dispensed in the outpatient pharmacies, and (9) ancillary services provided to patients (for example, physiotherapy, dietary, etc.).

b. Provide any appropriate part or all of these data, on demand when necessary, in the form of printouts or visual displays to (1) the physicians for patient care, and (2) the administrative business offices for patient accounts.

c. Provide administrative functions, such as (1) scheduling of patients and procedures in the health services system, including outpatient appointments and registration; hospital admissions, bed census and scheduling; and scheduling for ancillary services (e.g., laboratory, dietary, surgery, etc.), (2) scheduling and control functions for personnel, supplies, and equipment, including hospital

staffing, inventory control, menu planning, automated equipment quality control, etc., and (3) message switching functions to multiple departments (e.g., laboratory test orders to and from nursing station to laboratory to medical chart room and to computer center).

d. Provide a data base useful for (1) investigators needing both patient and inverted files for clinical, epidemological, and health services research, (2) administrators for health services evaluation, simulation, projection and planning, and (3) medical education.

e. Satisfy legal requirements.

EXTRAORDINARY REQUIREMENTS FOR MIS

It will probably not be possible in this decade for small medical groups or hospitals to provide the extraordinary amounts of capital, technology and organization necessary for MIS. These uncommon requirements for large technological systems, discussed by Galbraith,[7] are:

a. Large commitments of capital for long-term investment: the more complex the technology, the greater will be the lead time from outset of planning to completion of system.

b. A staff that is sophisticated in medicine and engineering, systems and computers. Experience has shown that failures of MIS have been due primarily to suboptimal mix of medical, systems, and computer specialists.

c. An organization of sufficient size, with effective management by technically sophisticated men who can make reliable decisions after considering technological alternatives. Large technological systems tend to commit an organization to a relatively fixed goal for a number of years. Such complex technological systems in medical care do not yet exist. Therefore they are innovative and entail great uncertainties, which result in large unanticipated costs of time and manpower. Flexibility in committing capital and other resources is required, to meet the inevitable deficiencies not foreseen early in the planning of a large project that is to extend over a long period. Since an investment in MIS is usually a very heavy one, a poor technical judgment can be disastrous.

PERSONNEL REQUIREMENTS FOR MIS

A complex medical technological system such as MIS requires a large "in-house" staff. In addition to medical and data processing personnel, the following qualified specialists should be included:

a. *Project chief:* a "physician-engineer" (i.e., an M.D. with training also in engineering, biophysics or computers) who has the confidence and support of hospital management. The great difficulties associated with interdisciplinary communications between physicians and engineers require at least one key person who has adequate expertise in both fields of technology. It is advisable to support the project chief with several physicians who also have some background in the physical sciences and who devote at least part time to the project.

b. *Systems supervisor:* preferably a physician familiar with the needs of the medical facility.

c. *Computer center manager:* a computer scientist with training in the biological sciences sufficient to enable him to communicate freely with physicians, who is responsible for design and implementation of the hardware and software for the central computer and its satellite processors and terminals.

d. *Information engineer:* one qualified in information science, preferably a physician, to develop the concepts and procedures for high-quality medical information processing.

e. *Medical systems analysts:* trained in analysis of medical subsystems, to define the needs and problems and to recommend alternative solutions. Good medical systems analysts are required if MIS is to be used for innovative approaches rather than for mechanization of existing manual methods. To facilitate interdisciplinary communication and maximize user acceptance, it is necessary to orient physicians, nurses, laboratory technologists, etc., in methods of systems analysis.[6]

f. *Applications programmers:* to write computer programs for the medical functions. It is desirable to train a pharmacist, laboratory technician, nurse, and physician, to function as programmers for their particular applications function in order to facilitate communications with other programmers not trained in the biological sciences.

g. *Systems programmers:* to design and implement the complex computer master control system and its related service programs to store, retrieve, and process patient data for the medical application programs. The systems programmers are also responsible for installing and monitoring the vendor's computer operating system software.

h. *Equipment engineers:* to work out problems of interfacing hardware from different manufacturers and maintaining the terminal equipment. Although the manufacturer usually maintains the major components of data processing equipment, it is necessary to have a resident maintenance engineer, trained on the selected terminal equipment.

i. *Orientation and training personnel:* to develop standard operating procedure manuals, and to orient and train MIS users in its operations. Successful achievement of objectives requires use of middle management hospital personnel in planning and implementing MIS subsystem components. To obtain user compliance for data input terminals as an operational part of a hospital service, whether nursing station, laboratory, or pharmacy, it is necessary to evolve the planning and the implementation of the terminal systems as an integral part of that hospital department's development. To develop data outputs with content and format of high utility to physicians requires careful planning. Regular meetings must be held at which the project chief meets with representatives of the departments affected. Intradepartmental orientation sessions should follow.

REQUIREMENTS FOR THE COMPUTER RECORD AND PATIENT IDENTIFICATION

A prime concept of MIS is that it is needed to serve as the central register and medical data repository for all patients eligible for care in the health services delivery system. The most essential requirement for MIS is an integrated computer record of all data from each hospitalization and outpatient visit of each patient. Small collections of patient data for subsystem components (e.g., blood banks, laboratories, bed census, etc.) will never satisfy medical services requirements.

To fulfill the need to handle many kinds of medical information covering many visits through time, the system must provide an integrated, variable length, variable format, computer-stored medical record.[8-10] Each datum should be stored once in its most fundamental unit of information. Then at any time it can be extracted according to any of various criteria, and grouped with other data or classified to satisfy the needs of any user. It is necessary to be able to retrieve on demand all or any specified portion of the individual patient's record (1) in chronological order by patient visits, or (2) by medical services (e.g., orthopedics, urology, etc.), and/or by clinical functions (e.g., history data, blood chemistries, etc.). Inverted files of data can best be generated for users on a scheduled basis.

Identification of each patient must be established for each visit to the health services system (hospital or clinic). Positive identification of the patient requires agreement on four identifiers: (1) encoding of each patient by a unique number, which may be a government-assigned number (e.g., the Social

Security number), or a locally assigned patient medical record number which will never be reassigned, (2) patient's name, (3) sex, and (4) birthdate (at least month and year). Any identification procedure using less than all four of these patient identifiers will probably have a significant error rate in record linkage for multiple data entries.[11] When medical record numbers are manually entered, a check digit procedure should be added.

Entry of patients' identification data by embossed or punched paper, plastic or metal cards, is essential to minimize the transcription and transposition errors arising from multiple manual entries. However, since people accidentally exchange identification cards, it is mandatory that at each registration the four identifiers be checked to verify that the encoded card does in fact identify the patient from whom the datum is being entered.

There is great need to work toward developing a means of positive identification of patients to be applied uniformly throughout the country.

EQUIPMENT REQUIREMENTS FOR MIS

a. Central equipment: An equipment configuration must be developed to permit patient data to be stored in and retrieved from the patient computer record, from remote terminals in the inpatient department and in the outpatient department.[8] The central processing unit and its core storage must be of sufficient size and speed to perform simultaneous multiple on-line tasks with a response time acceptable to the users.

A basic requirement of MIS is that it should provide reliable service to physicians, 24 hours a day, seven days a week. Accordingly, sufficient redundancy of equipment must be allowed to provide continuing service despite equipment breakdown. Until improved economy in equipment is developed, complete redundancy to provide full 24-hour service may not be economically practical.

Storage devices for the large central data base must be of sufficient size and speed to permit access to the data for any patient in the health services system within an acceptable response time. Three levels of storage devices appear to be required for the data base itself.

(1) Billion to trillion bit storage,[12] with one-half to one second random access time for all active medical files, for patients eligible to use the health service system;

(2) Millisecond access (disc or drum) magnetic storage for active files of patients currently in the hospital or receiving outpatient care;

(3) Magnetic tape drives for archival storage of inactive patient files, for backup records of transactions of patient data, and for batch-processing of data.

Large disc storage files are also necessary for reference data sets (drug compendia, dictionaries, thesauri, etc.) and programs not located in core or extended core storage.

b. *Peripheral equipment:* Selecting suitable terminals acceptable to professional users is a critical requirement for MIS. The severest demand on the system is that physicians and nurses must be able to enter patient data directly into the computer via acceptable terminals. For example, instantaneous response is necessary for on-line monitoring of patients in intensive care units. At nursing stations, physicians may enter medical orders using interactive terminals, by selections from visual displays of multiple choice formats, and if the displayed response appears within one second this appears to be acceptable. Laboratory technicians and pharmacists may accept a slightly longer response time, but certainly no longer than three seconds. Printouts of patient data on demand in the record room may take several minutes. Routine reports may be batch-processed off-line. It is advisable to consider the necessary response time for each application so as not to establish unnecessary requirements for the system.

Terminals must be ample in number to avoid an intolerable amount of queuing; a 200-300 bed acute general hospital may require 50 to 100 terminals. Terminals must be tailored to the needs of each user. Physicians will not accept typewriter keyboards; but they will accept voice communication to medical transcriptionists[13] and touch-wire or light pen visual displays;[14] and it is hoped that the future will also bring into use visual phones. Pharmacists will accept typewriter keyboards and laboratory technicians will accept, for certain functions, push-button keyboard input devices.

A small peripheral computer will usually be required as a satellite to the central computer for operation of terminals, storage of display formats, maintenance of local hospital patient and specimen schedules and status, and for message switching (e.g., laboratory data to nursing stations and to computer medical record). The peripheral computer must be of sufficient size and speed to maintain acceptable response time for a large number of peripheral terminals. Small dedicated computers will also be required for high density data generators such as large automated chemical analyzers and intensive care units. Compatibility between computers is an essential requirement so that data can be transferred between the central and satellite computers.

In addition to on-line modes of data input, the system must be capable of accepting information from a variety of sources, including mark sense cards, optically scanned forms, key punched cards, punched paper tape, etc.

c. *Software requirements:* Systems programs must be developed to handle multiple medical functions (subsystem components) simultaneously, permit teleprocessing between the central and peripheral processors, enter and integrate the data into a specific patient computer record in the central data base, then retrieve the data from the same patient computer record almost immediately, in accordance with various clinical needs.

The software requirements for an integrated file-oriented data processing system have been implied in the section on *Requirements for the Computer Record and Patient Identification.* It thus becomes necessary to develop a general programming system to store, process, and retrieve all kinds of patient data. This has to include routines for the handling of direct access storage, remote terminal and input/output devices, on-line in real time, in addition to off-line batch processing. Various separate medical applications or functions must be treated in a modular fashion, adding the functions to the system as needed.

Programs may need to be written in low level (assembly) languages to result in maximum economy of time for routine repetitive real time procedures performed many times each day. In some instances, higher level languages must be used which permit programmers to write, enter, and debug applications programs directly from remote terminals, and to perform numerous storage, retrieval, and message switching operations using a relatively small number of program statements.[10]

Error correction, recovery and restart programs must be developed. Error checking programs should include checks for missing data, check digits for patient identification numbers, validity limits for laboratory and other digital data, etc.

Postinstallation programming will be required to continually improve operational and control procedures, file maintenance, backup system maintenance and unanticipated problems.

Documentation of procedures and programs must be adequate to facilitate maintenance programming, reprogramming, and transferability to other systems.

RELIABILITY REQUIREMENTS FOR MIS

It is a critical requirement of MIS that it must perform with a reliability of almost 100 percent. That is, a physician must be able to enter and retrieve

patient data any time of day, seven days a week. To the user, "reliability" means the percentage of time the terminals are operating satisfactorily. Equipment and equipment components integral to MIS should perform with an individual reliability of 98 percent or more, or an equivalent "down" time of less than one day in 50. It is therefore essential to have a proper mix of backup equipment, modules, parts and corrective maintenance capability to maintain operations despite failure and breakdown. A periodic preventive maintenance program is also required. Alternative backup procedures provide a second means for maintaining continual system operation.

It is required that the system provide backup capabilities for both hardware and software. Thus the central computer and peripheral terminal equipment should be duplicated and comprise two paired systems which functionally resemble one another; by circuit switching, one unit provides backup in case of failure of the others, so as to provide a "fail-soft" system. All terminals should be paired at each user station, so that one-half of the terminals are active in case one system fails. Paired remote terminals should use independent telephone lines to the computers so that if one telephone line is interrupted, at least one terminal always remains active at each user station. Terminals should be "plug-in" movable modules, so that they can be easily repaired, or replaced by a standby terminal.

A noninterruptible power supply is necessary in case of electric power failure. Such a system[6] requires four major components: a constant voltage battery charger; storage batteries; static inverter, and a diesel engine generator. One method of operating is for the AC line to supply power to the static battery charger which in turn "float" charges the battery, and at the same time supplies DC power to the static inverter, which supplies AC power to the AC load. If normal AC power failure occurs, the battery continues to supply power to the inverter in order to sustain the AC load without any interruption. Because of the limited time the battery can power the total hospital system, the battery system is supplemented by the diesel engine generator. When normal AC supply is restored, the load is automatically transferred back to normal power.

The air conditioning system for the computer central and peripheral processes must comprise at least two independent units. Thus, if one unit fails, the second is capable of fulfilling minimal cooling to maintain temperature control at a level that will prevent computer failure.

Backup records of data transactions must be logged on magnetic tape and/or disc storage at critical points in the data communicating system so that in case

of failure, the data are not lost and the patient computer record can be updated or even reconstructed, if necessary.

It is a common experience that most down-time occurs when equipment or programs are replaced or modified; at such times one must be especially alert to use the backup and recovery systems.

CONTROL REQUIREMENTS FOR MIS

a. *Data quality control:* Much of the quality control for MIS is editing of incoming data for validity at the input level (e.g., automatically checking patient's identifying data against his existing computer record at time of office visit registration or hospital admission; checking validity limits of laboratory tests against standard definition tables at the time of entry of test value, etc.).

On-line data entry permits immediate error detection and correction at source. An error detected at a later time is usually difficult to correct when the professional user who generated the input no longer has readily available the relevant source data. As included under *Software requirements,* programmed error surveillance procedures should scan all data at input for missing or logically invalid data and notify the operator and/or user when such errors are found.

A prime concept of MIS, therefore, is that all data should be entered directly into the computer from source. Avoiding the use of intermediary personnel decreases errors and information loss. Physicians should enter their medical orders directly into the computer. The use of clerk technicians to enter into a hospital information system the medical orders handwritten by doctors, is merely to mechanize a traditional manual operational mode. Similarly, pharmacists should enter prescriptions directly into the computer and verify the label printout, and not work through clerk typists. Physicians should enter their diagnoses directly into the computer by selecting the best fit from a structured terminology; this avoids coding by record librarians.

b. *Patient data confidentiality:* A prime concept is that all data within the patient computer record are subject to the same regulations governing their privacy and confidentiality as are data in a hospital record room.[15] This requires controls for protection of the computer records to specified degrees of user-imposed privacy; controls whereby a physician is required to identify himself, so that a specific patient's data will be released only to the physicians responsible for the care of that patient. Psychiatric data require additional special controls so as to be released only to the specific psychiatrist responsible

for the patient. Research data require identification of the principal investigator; epidemiologic research on groups of patients requires maintenance of the privacy of individual patients so that data are distributed only in aggregate form.

UTILITY REQUIREMENTS OF MIS

User acceptability is enhanced if MIS is so designed as to be capable of smooth integration into the professional activities. Terminals must be selected which are acceptable to each user category (see *Equipment Requirements*). MIS procedures must be developed with and by the users themselves to increase acceptability and decrease required orientation and training. Key physician personnel are required to participate in planning and implementation. A well-planned period of training of users will greatly enhance acceptability of MIS.

For visual display users, probably three different programs will be required: (1) orientation displays with detailed instructions and a small amount of information in each display sequence; (2) routine user displays for experienced users with fully loaded displays and only minimal essential instructions, and (3) personalized displays for frequent high volume or high priority users with custom tailored displays that permit entering full pages of routine orders with maximum speed.

It has been emphasized that a prime concept of MIS is that all users shall enter their patient data directly into the computer. On-line verification of data entered into the patient computer record by the one who generated the data minimizes errors and insures highest quality data.

ECONOMY REQUIREMENTS OF MIS

The special needs of MIS result in increasing requirements for terminals, which usually eventuate in more expenditures for peripheral than for central equipment. Also the increasing requirements for time sharing and real time processing usually result in more costs for software than for hardware.

It is essential to plan for obsolescence. New hardware and new software will continually be developed; but to achieve an economical cost/performance ratio, management must make a decision at some point in time to "freeze" the system design for a number of years in order to devote its resources to the

users' needs rather than to the system's needs. Then perhaps in four or five years the expense of another iteration of system improvement will be acceptable in order to take advantage of interim innovations.

Costs must be determined for (a) implementation of MIS hardware and software, and (b) its operations, including cost of MIS per hospital day per patient, and cost per day for each patient in the health service system. It will be important to establish with the hospital accounting services, a cost evaluation center to achieve these objectives.

Because of the large initial investment in hardware and software, it is yet to be determined what the impact of MIS will be on hospital costs;[2] nevertheless, as a minimum, the computer should improve efficiency by making manageable a larger information load at the same costs. It is also evident that medical data can be transmitted faster via a computerized system, thereby decreasing personnel waiting time. Furthermore, the computer should help nurses and technicians to avoid errors.

It is possible that technology may not decrease the number of personnel, but it will change job content, increase productivity, effectiveness and quality.[16]

TIME PLANNING REQUIREMENTS FOR MIS

A complete MIS will require several years to implement. It is such a large, complex medical technological system that it will not be possible to implement a complete MIS at one point in time. It is prudent to establish attainable objectives with realistic time tables. Accordingly, MIS is usually installed in a modular fashion. Hospital business functions, hospital admission and bed census, clinical laboratory or pharmacy services are usually initiated first, then other subsystem components are added. This requirement for modular implementation results in a long lead time in achieving an operationally complete MIS.

It is a critical requirement that the data from each module added to MIS be compatible, in order that they may be entered into the central patient computer record; all patient files will then be integrated.

Assuming that the project staff has been acquired, each modular function subsystem will require a time schedule that will: (1) define precise objectives, (2) conduct functional analyses of information load (volume and characteristics), and personnel information handling (output specifications and time responses), (3) determine subsystem configuration, (4) obtain

management approval for selected design, (5) order equipment, (6) write and test programs, (7) prepare facility for equipment installation, (8) install, test, and debug equipment and programs, (9) prepare users' manuals and conduct training of personnel, (10) conduct pilot operational test, (11) implement operational subsystems, (12) evaluate performance, and finally (13) revise, modify, and improve as needed.

Time schedules should be provided for both management and the project staff in sufficient detail for each subsystem component for each milestone date, so that all can check progress against projected date, and accomplishments can be reviewed at critical points in order to ascertain that the system will achieve its objectives and meet functional and performance specifications.

REQUIREMENTS FOR THE FUTURE FOR MIS

In the next five years, research and development[18] should be extensively supported for:

a. Determining an effective size of regional computer centers for medical information systems for groups of cooperating hospitals and health service systems.

b. Determining a more efficient organization for computer stored continuing medical files, oriented to both patient care and medical research.

c. Developing new, super-mass, random access, storage files to handle the immense amount of medical data generated from a community of patients.

d. Developing more efficient and acceptable terminals for physicians and other personnel to communicate with the computer. Graphic displays will become essential for high density data outputs and even pictorial displays will be desirable.

e. Developing improved communication systems for transmitting compatible data between medical centers within a region; without such improved systems, for medical facilities a few hundred miles from the computer center, communications costs may exceed data processing costs.

f. Developing means of positive patient identification to be applied uniformly throughout the country.

SUMMARY

The general requirements for planning and implementing a medical information system are extensive. Extraordinary requirements exist for capital,

personnel and organization. The stringent requirements for high reliability and user utility for a real time system greatly increase hardware and software needs. The magnitude of the system necessitates careful time scheduling and modular implementation.

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EVALUATION TECHNIQUES FOR MEDICAL INFORMATION SYSTEMS

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INTRODUCTION

How shall we evaluate a medical information system? What criteria are meaningful and what are measures of those criteria? To answer these questions, we must look at the elements and activities of the health services supported by the information system, its clinics, hospital nursing units, the diagnostic and therapeutic processes. In so doing, one can identify several kinds of evaluation criteria applicable to the information handling of the over-all health service system. From a societal point of view, the most expressive criteria are economic – what are the contributing values or utilities of the information system and the costs they incur? A second set of characteristics, vital to the physician and administrator, are cybernetic – how well does the information system function in observation, analysis, communication, control and planning? A third set of variables relates to human factors – how compatible is the information system with the perception, the capabilities, and motivations of people involved?

Theoretically, the human factors could be included in the cybernetic function, but it is useful to treat them separately. A medication error on a nursing unit may occur through failure of transmission of the order, or it may occur because an overwrought nurse misread a drug label. The result for the patient may be the same, but the evaluation and correction are to be sought in different ways.

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Another point of theory: the consideration of economic criteria leads us unavoidably to cost-effectiveness analysis. The medical information in an evolving health care system has as a controllable variable the scope of information to be gathered and operated upon. Each configuration of data acquisition has its own set of benefits and costs. It is possible that a potential innovation may replace an existing procedure only because its performance cost is lower, but even here it is difficult to avoid simultaneous consideration of some other variable benefit, say precision or reliability vs. cost. In general, the appropriateness of cost-effectiveness evaluation (comparative cost analysis of alternative means for performing a specified communication process) is inversely related to the amount of decision-making under uncertainty that is involved in information usage; or, to put the point in another way, such appropriateness tends to be directly related to the degree to which decision-making is a matter of mechanical response.

ECONOMIC CRITERIA

On the surface, economic criteria for judging whether an information system should exist at all, or whether certain elements of information should be gathered or not, are simple to state. An element of information should be gathered and acted upon if the value resulting from the action taken exceeds the cost of gathering the information. The value of information is inextricably related to the net value of medical action taken as a result. The word *net* is inserted in the statement to imply a number of components of value involved in a decision and action, not all of them positive. The net value of a diagnostic test, for example, contains not only the benefits resulting from detection of the true positive cases, but the loss involved in the false positive cases as well. A first stab at evaluation of any particular information element in a screening or diagnostic system is to assess the changes it will cause in the number of (or probability of) detection of new cases and the change in number of false positives unnecessarily followed up. These measures are useful only if some cost and value estimates are available also, and here the difficulties of the problem are revealed.

The elements of a medical information system imply cost and values over a range of time, and to a number of agencies and people. The person for whom a measure is made may benefit (or suffer loss) immediately as a result, or perhaps in the long run when the measure is compared to an updated one. Thus we

must consider the value of present good and the discounted value of future good. The good may accrue to the individual measured, to the medical care system responsible for him, and to society at large in the form of the individual's contribution to society (or the removal of his threat to society if we are speaking of a communicable disease). To the extent that the element of information is used also to build a statistical data bank – to increase the precision of interpretation for others – further potential for public good is created.

The burden on the evaluation process in dealing with economic criteria is *definitiveness* – recognizing all the elements of marginal cost incurred and value derived from an element of information added at a particular time. Short-term and long-term decisions, and public and private good, tangible and intangible, all are part of the picture.

The fact that quantifying all of the components of value may be both philosophically and practically infeasible does not necessarily mean that a favorable or unfavorable evaluation about a particular measure is difficult. We may not be able to say how valuable a piece of information is, but all we need to say is whether it is more valuable than the cost incurred by its acquisition. Statistical decision theory is a logical approach to evaluation of information when that information is used to reduce the uncertainty in a decision process.

However, information flow in a medical care system serves other purposes than medical decision-making. It signals actions of many kinds in the carrying out of specified tasks. The larger and more complex the organization, the more dependent it is on its formal communication processes. The cybernetic aspects of sensing, communication, and control must be evaluated for their contribution to the processes that follow medical decision-making.

CYBERNETIC FACTORS

A medical information system does not itself confer medical benefits or perform other useful work. Its value lies in its role as part of a total purposeful system; it facilitates and enables other elements of the system to achieve objectives. An evaluation of the information process must take into account, in addition to the adequacy of information content, the dynamics and accuracy of information flow and the ease with which the information may be made to serve a wide range of functions.

Using a cybernetic model to develop evaluation criteria, we can examine the three sequential processes of (1) observation or sensing, (2) interpretation or analysis, and (3) action to maintain specified norms or to attain goals. Some element of self-evaluation is assumed to exist in a stable system if part of the sensing mechanism is directed to the effect of actions taken; thus the three steps become a continuous sequence.

In a medical information system the observation and sensing function may be the physician's knowledge of signs and symptoms of patients, the nurse's awareness of patient needs and the level of resources available, the administrator's tally of supply inventories and availability of beds, the trends in occupancy and the long-term expectations of the public and the staff.

The analysis function is represented, for examples, by the physician's diagnosis and evaluation of therapy, by the advice rules of a screening clinic, by the nurse's preparation of care plans, by the ancillary service and logistical support policies, and by the planning for growth and adaptation to social change.

The action phase is represented by a physician's preparation of orders and by the response of other elements of the system to them. In the short term, the activities of administrative and ancillary services may be considered as the response to action signals generated by communications from physicians and nurses engaged in the central actions of patient care. In the longer term, the actions observed may be responses to administrative decisions to expand or to change facilities and functions on the basis of changes in needs forecast or change in goals.

All three functions of observation, analysis, and action are, or contain, information handling and communication activities. A failure of communication between any pair of functions may result in system failure. Such failure may occur because inadequate or inappropriate information is conveyed, because information is not conveyed in time, because of errors in communication, or because information is not collected and stored in form to permit relevant analyses. From this brief description of information's role in the organization process, some criteria are apparent: completeness, timeliness, reliability, operability, and cost. For each criterion, measures must be developed to evaluate the information system with respect to the various functions it serves. The evaluation problem can be expressed as a matrix of measures of effectiveness for each criterion and set of functions, for example in Figure 1.

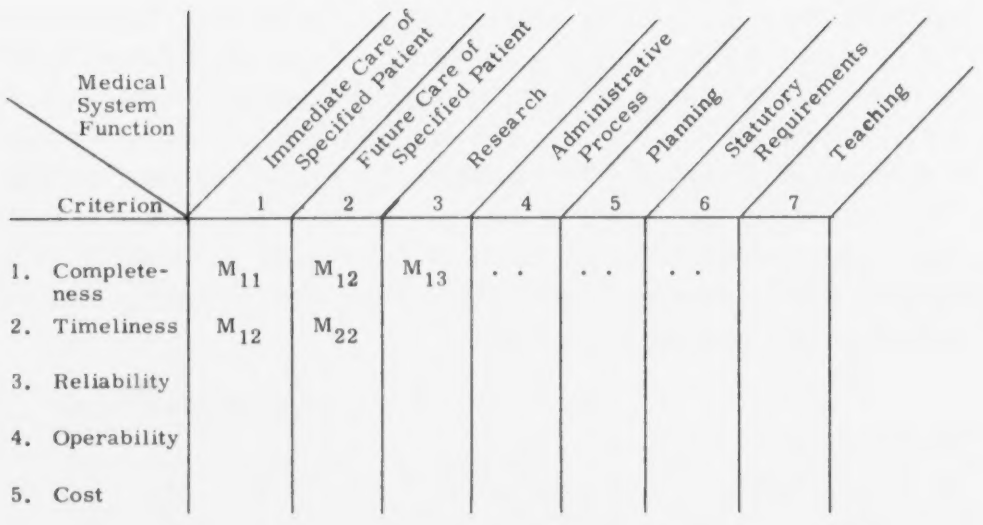

Figure 1. Cybernetic criteria of information systems.

To be useful there will need to be such matrices for major activities, e.g., patient admission, diagnosis, medication, radiology. Expression of the evaluation process in this way presents a formidable picture of work needed to be done. For most elements, the matter has yet to be given formal consideration. Nevertheless, there are some interesting examples of measures developed for several of the criteria.

Lieberman[1] has proposed a scheme for relating classes of information gathered on source documents to such coalitions as forms and reports. By a matrix presentation, the presence (denoted by 1) or absence (denoted by 0) of a class of information in a set of source documents is displayed. Similarly, the availability of source documents to reports, and in turn, reports or forms required by service functions, is displayed. By matrix operations, it is possible to determine completeness – that all classes of required information are made available to the function, and redundancy – the number of duplications.

Hsieh[2,3] has adapted the procedure to evaluation of a hospital medication system, treating the criteria of completeness, reliability, and cost (or efficiency).

Completeness

In a matrix, the elements of information and paperwork forms available for a given function, say direct patient care, first become row headings, while

paperwork forms alone become column headings. The element of information "patient name", for example, is represented by 1 if recorded on a form, by 0 if not. The availability and use of one form to prepare another is denoted by 1, or by 0 if this linkage does not exist. The diagonal elements in the form section of the matrix are listed as -1 for the purpose of performing a column operation which will reveal the number of times a particular data element is made available (or recorded) for the function. An example is shown (Fig. 2), displaying a set of elements of information used in some medical function, and the forms used in carrying out the function.

	System Matrix			Column Operation Matrix				
Data Elements	F_1	F_2	F_3	1	2	3	4	
d_1 - Patient Name	1	0	0	0	0	0	3	
d_2 - Date	1	1	1	0	1	3	6	
d_3 - History Number	1	0	0	0	0	0	3	Solution
d_4 - Diagnosis	0	0	0	0	0	0	0	
d_5 - Physician's Name	1	0	0	0	0	0	3	
Forms								
F_1 - Doctor's Order	-1	1	0	1	1	3	0	
F_2 - Nursing Care Card	0	-1	1	1	2	0	0	
F_3 - Medication Ticket	0	0	-1	1	0	0	0	

Figure 2. System matrix and column operation.

The column operation is displayed to the right of the system matrix, beginning with a Column 1 of 0 for data elements and 1 for forms. Adding this column to the last column of the system matrix produces Column 2 of the column operation matrix, which has a 0 in its lowest element. The next step is to multiply the second column of the system matrix by whatever factor (in this case 2) is required, when elements are added to Column 2 of the operation matrix, to reduce to 0 the next-to-bottom element. Finally, the first column, F_1, is multiplied by whatever factor is required to reduce to 0, when added to operation Column 3, the top element of operation Column 3. The column elements above then constitute the solution and show the number of times each data element has been recorded from source on a form, or has been simultaneously available from another form. In the example, one sees the datum d_1 handled six times, while diagnosis d_4 does not appear at all. This may satisfy completeness requirements for one function but not another. Where

reliability of recording and transmission is low and importance of a data element is great, the elements in the solution column in the operation matrix may ideally be greater than 1. A figure of merit for completeness for each function will reflect the fraction of data elements in the system whose availability equals or exceeds the ideal.

Reliability

A figure of merit for reliability of an information system is relatively easy to form although difficult to measure. It can be expressed as the probability of accurate survival of information as it flows through the administrative system. Data passing through n stages of transmission, each with some known or estimated probability of correct transmission, will have an over-all probability of accuracy equal to the product of the independent stage probabilities. The notion of reliability is discussed by Herwald.[4] The techniques for experimental detection of failure in a hospital medication information system have been reported by Barker and McConnell,[5] while Hsieh[3] reports some comparative reliability data for hospital medication systems of approximately 80-85%.

Cost

The original matrix representation of linkages (an additional reference for this approach to evaluation is the network approach of Busacker and Saaty)[6] can be used to quantify the redundancy of recording and transmitting information, which, after making allowance for the value of redundancy in some circumstances of relatively low reliability, is a measure of inefficiency of communications resources. Hsieh[3] has defined efficiency as the ratio of the number of links in the ideal system to links in the actual system, as computed in the process of determining the completeness measure.

Timeliness and Operability

The criteria of timeliness and operability are to some extent bound up in the measure of completeness. As described, that measure may be made by examining data sources and forms relative to the informational needs of a particular function, thus reflecting the potentials of an information system. A measure of timeliness – say the frequency with which a necessary element of information reaches its destination in time to influence action – must in part

come from empirical observation. Failures of timeliness may be observed by the critical incident technique. Safren and Chapanis,[7] in an analysis of medication errors, noted some double dosages, errors traced to time lags in the communications process. Unfortunately, critical incident techniques do not yield measures of absolute frequency of events, hence do not lead to a measure of effectiveness based upon frequencies or probabilities. The critical incident approach (see Chapanis[8]) is, however, in itself an evaluation technique if the course of an incident relates to a general property of the system under study. This line of thinking leads to consideration of the human role in the workings of the information system, thus leading us to a set of criteria for human factors.

In the Safren and Chapanis[7] study, all of the errors were in some way failures of communication; however, they involved not only the formal or mechanical information system processes, but some lapse in the human handling of information. Failure to recognize drug name or to see a decimal point on a small label, miscalculation of dosage, omitting a medication: none of these are inexorable system failures but are affected by capacity for perception under stress, motivation, understanding, and other attributes of the human participant. They are also functions of system design and one can speculate on some tangible attributes of an information system that would reflect its vulnerability to human fallibilities ranging from sabotage and ignorance through the failures of perception under stress experienced at times by the most highly motivated and skilled person.

Rather than depending upon numerical measures of effectiveness, the evaluation of an information system from the point of view of human factors may consist in noting the presence or absence of those attributes that mitigate or protect against human error. Are parallel redundancy links provided where probability of human error is high? Is exception reporting built in so that widely erroneous data are recognized? Are the dynamics of the system protected by reminders, such as tickler files? Are displays to human beings presented in symbols and forms established as good human engineering practice? Is the environment of human participation in the information system process designed and timed to minimize stress?

CONCLUSION

We have sketched briefly some approaches to formal development of economic, cybernetic, and human factors criteria for evaluating medical

information systems. Some measure of effectiveness or figure of merit has been suggested for each criterion. However, a major problem remains: what costs or values are to be associated with these measures? The need for such cost and value estimates is obvious in the fact that several of the measures of effectiveness are traded against each other; e.g., increased redundancy improves reliability but increases cost. Figures of merit may be useful in showing the ways in which one alternative system is better or worse than another; but in the long run, we must assess the relative values of these measures on a common value scale.

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EVALUATION
OF A MEDICAL DATA SYSTEM

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INTRODUCTION

More than a century ago John Stuart Mill[1] said that "art is the heart of science." No systematic endeavor exemplifies the potential of art in science so well as the process of evaluation.

Thought is changing about research and development methodologies and unconventional applications of these methodologies to our problems of life are being tried. Possibly, a "spontaneous consensus" is occurring to take Lorenz'[2] admonition seriously, that is, the only way to beat the trap of convention is to clearly set forth a problem, state what we believe are its causes, then test the reverse.

If we do not abandon mere convention in our efforts to better understand and control the undesirable effects of complex events, a risk is run of making evaluation result in tyranny and not in benefit, as Weckwerth[3] suggests in a paper titled "On Evaluation: A Tool or a Tyranny."

In explaining his view, Weckwerth offers four important points for putting evaluation in perspective. These are:

"(1) There is no *one* way to do evaluation.

"(2) There is no generic logical structure that will assure a unique right method of choice.

"(3) Evaluation ultimately becomes judgment and will remain so, so long as there is no ultimate criterion for monotonic ordering of priorities; and:

"(4) The crucial element in evaluation is simply: who has the right, i.e., the power, the influence, the authority, to decide."(And I add, how such persons are, at any given time, predisposed about a given issue).

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It is clear that Weckwerth is at least implicitly in tune with Mill. Weckwerth specifies areas in which evaluators must become skillfully artful if the results of their efforts are to have any consequence. For evaluation to benefit practitioners it must be an integral part of system management and modification rather than simply a fact finding and/or problem solving device. When an evaluator singly focuses on solution to problems, he can very well discover a solution to a given problem without a hint of the new problems his solution creates. If the evaluator keeps sight of the part his results play in systems management and change, he enhances his own understanding of process, and his skill in its assessment. Armed with integral results about workings of the system, the evaluator is a resource to the decision maker.

With these issues in mind, an Evaluation Plan was devised for assessing the benefits of an automated, patient care oriented, hospital information system. This development program is called the Medical Data System (MDS). The remainder of this presentation covers:

(1) a brief description of that plan;
(2) a survey of some results from our first baseline study; and,
(3) development of an evaluation model.

EVALUATION PLAN

The immediate task of MDS evaluation was to develop baseline data for comparison of hospital operations before and after installation of an automated medical communications system. Before-after contrast of operations provides for a short range test of the new system's relative ability to increase: message legibility; speed of dissemination; control over information flow; ability to handle greater volume; reliability and accuracy; and cost benefit; while decreasing unnecessary use and duplication.

In the longer range, the valuation was planned to: gauge effectiveness of care delivery; measure utilization of resources; use the data base in planning future hospital services, and in conducting education and training programs; and develop a forecasting tool (simulator).

In order to create a data base relevant to our longer ranged objectives and provide a tangible goal orientation for immediate objectives, certain relational descriptors were adopted. These description statements directed evaluation planning and set analytic strategy. These descriptors are: (1) patient group–identified by observably differing needs; (2) care programs defined in terms of operations; (3) specific operations linking care programs and specific patient groups.

Analysis of data in terms of these criteria has yielded results useful in quantifying workload requirements generated in the hospital* by different patient groups.

By way of conceptual position, it should be noted that this evaluation views the hospital primarily as a human system. Terms of conception derive mostly from social science. Tenets drawn from psychological ecology and economics serve as base for interpretation of results. First analytic efforts focus on specification of staff behaviors (and their constraints) which are considered basic for accurate prediction of workgroup specific man-hour expenditures at various locations in the hospital.

Although the evaluation effort was by no means limited to a study of manpower, this presentation concentrates on manpower expenditures in patient care communication. The investments by hospitals in information commerce is tagged at 25-30% of total operating cost in the literature[4,5] and at 35-39% from our studies. In our study hospitals, about half of this cost is attributable to manpower. What is more important is that staff behaviors associated with information exchange are integral to and critical for the present and future health status of patients. In short, persons' lives depend upon message clarity, accuracy, relevance, and speed of transmission. These features of information commerce are the behavioral products of staff employing the hospital's communications network. Considering the centrality of manpower and its sizable cost, it is a profitable place to begin analyses.

EVALUATION DESIGN

Consistent with immediate and longer range goals, baseline data represent: (a) conditions of communications commerce under manual operating mode at the MDS installation hospital (KFH-San Francisco); (b) conditions of communication commerce under manual operating mode at two control hospitals (KFH-Oakland and KFH-Walnut Creek). Data collection is planned as an annual event allowing comparison between manual and automated systems at the installation facility and against manual operations (through time) at the control facilities. The first round of data collection occurred in April-May 1969.

Planned comparisons entail tests of relative economy, timeliness, reliability/accuracy, completeness, and utility (for staff) of the information system.

*Three hospitals studied were: Kaiser Foundation Hospitals (KFH) San Francisco (296 beds), Oakland (278 beds) and Walnut Creek (201 beds).

Direct observation of operating conditions is the primary source of data. Observations are organized in terms of patient care and communication as determinants. These determinants provide two principal dichotomous dimensions: Patient Care and Non-Patient Care; Communication and Non-Communication.

For study purposes, *Patient Care* is defined as goal oriented, behavior setting (e.g., nursing unit) limited activity that is performed on behalf of specific patients. *Communication* specifies sets of behaviors that represent information processing, e.g., reading, writing, conversing, etc. *Process* behaviors specifically link special purposes behavior settings (e.g., laboratory, pharmacy), to core settings (nursing units).

Observations were designed to capture patient centered information in terms of what staff members did, for which patient, where, when, how, and how long they took. Particular attention was paid to patient care communications within core settings (nursing units) and between core and ancillary settings (laboratory). Transmissions within and between subsystem settings are viewed as time and effort (work) generating events.

Key events (decisions) joined in sequence with conditional events (subsequent steps) which terminate in feedback messages constitute process loops with real time properties. These loops represent functional integrations of subsystems. How well integrated are subsystems is measurable by examination of work flow, various delays, and timing of steps in process loops.

One final data area needs description: relative utility of information systems for staff involved in delivery of patient care. Utility is expressed generally in two ways in our evaluation:

(1) Staff's use of "bypassing" behavior (a bypassing behavior constitutes use of an extraprocedural means for achieving an end);

(2) problem recognition by staff (particularly those staff directly responsible for the delivery of care).

SURVEY OF RESULTS, APRIL-MAY 1969 STUDY

Analysis of staff time and effort shows that the proportions of time spent in patient care-communication was relatively consistent across facilities. The proportion of time spent was somewhere between 25-30% for all work groups. When distribution of time and effort between major study activities, i.e., patient care-communication; nonpatient care-communication; patient care-noncommunication; and nonpatient care-noncommunication was examined, workgroup and hospital variations were observed. Examination of

doctor and nurse groups shows characteristic expenditures of time and effort for each hospital.

For example, staff doctors at KFH-San Francisco spent 21.6% of their time in the hospital in contact with patients and 58.7% communicating about them. The pattern for staff doctors at KFH-Oakland was 14.4% contact and 75.7% communication. Proportions for Walnut Creek were 15.8% contact and 68.1% communication.

Similarly, staff nurses showed pattern variations. Patient communication and contact proportions were: 34.1% and 35.5% KFH-San Francisco; 47.8% and 26.7% for KFH-Oakland; and 43.3% and 33.8% for KFH-Walnut Creek. KFH-San Francisco was comparatively high contact, low communication for both doctors and nurses.

Certain dimensions were found to significantly differentiate staff time and effort expended in patient care communication. Important among these variables were: *medical specialty* (which in part delineates a patient's location in the hospital), *day of patient stay,* and *relative patient condition* and *mobility*. Herein, patient mobility signifies whether the patient is adjudged *bedfast,* has *limited ambulation,* e.g., bathroom privileges, or is *ambulatory*. *Time of day, day of week* and *time of year* also differentiate expenditures of effort. Space limitations permit only selected examples of these influences.

Consider the distribution of doctor time and effort devoted to patient care communication by day of stay on medical services in the three hospitals. It can be generally said from Figure 1 that relatively greater proportions of patient care communications occur early in a patient's stay on medicine, diminishing on subsequent days of stay, with periodic fluctuations which probably represent some decision cycle.

When doctors' patient care communication was analyzed in terms of relative patient mobility by day of stay on medical services, cyclic behavior was observed. This is exemplified in Figure 2 for KFH-San Francisco (similar tendencies were noted for the control facilities). It is speculated that this pattern (or rhythm) characterizes differential system reactions to variations in patient condition.

Another patterned systems response was observed when initiation of doctors' orders for laboratory, drugs and x-rays was examined by day of patient's stay on the medical service. Figure 3 for KFH-San Francisco is an example. Distributions for KFH-Oakland and Walnut Creek were remarkably similar.

Figure 3 shows that 25-30% of doctors' orders covering drugs, x-ray and laboratory tests were originated in the first patient day. Another 15% were

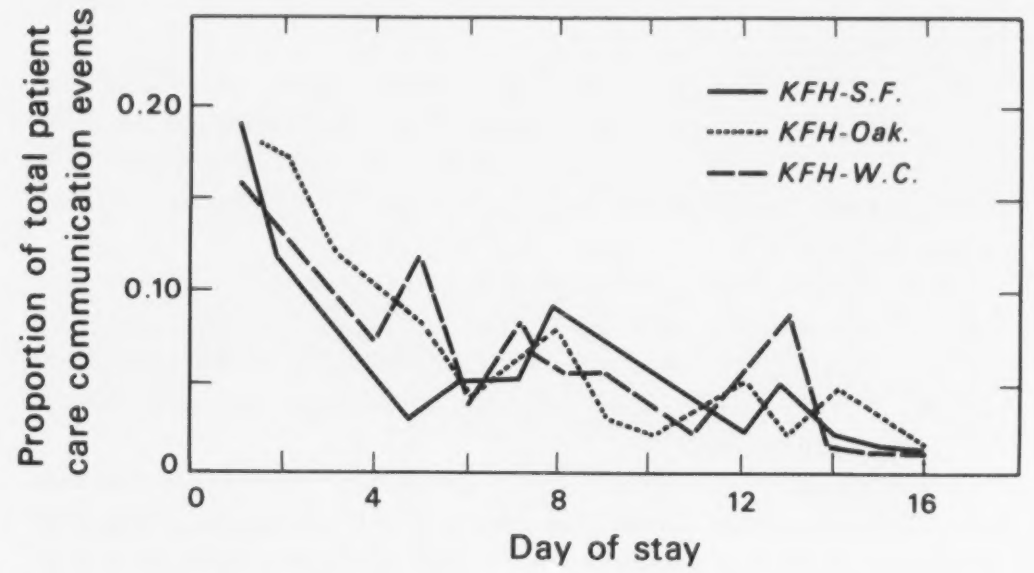

Figure 1. Distribution of patient care communication by doctors, by day of stay in three hospitals.

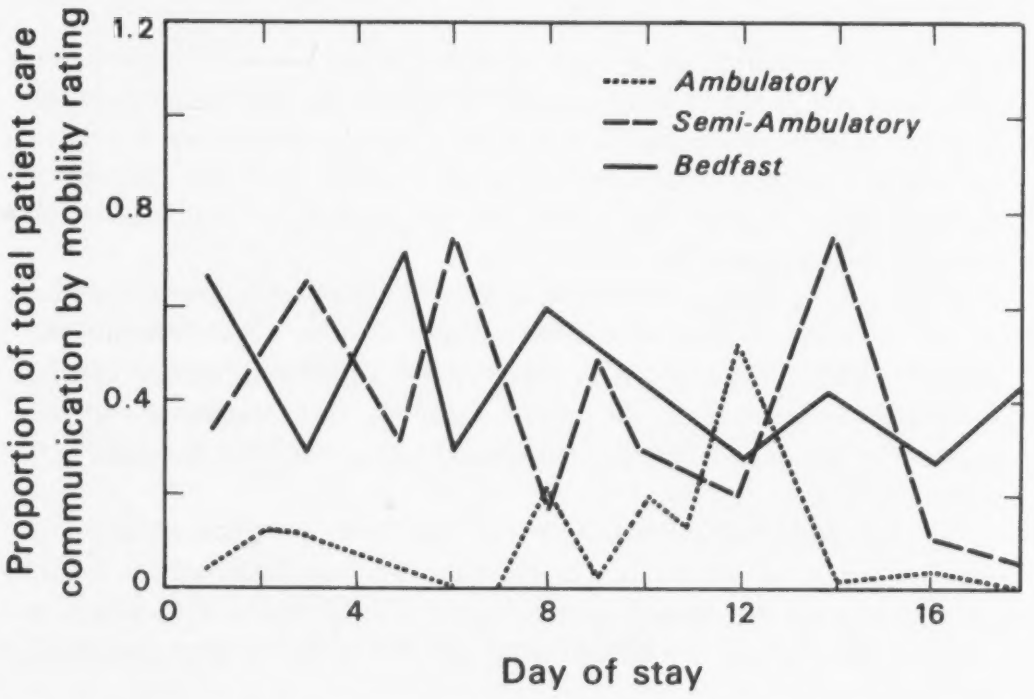

Figure 2. Distribution of patient care communication by doctors about bedfast, semi-ambulatory and ambulatory patients by day of stay on the medical service KFH-SF.

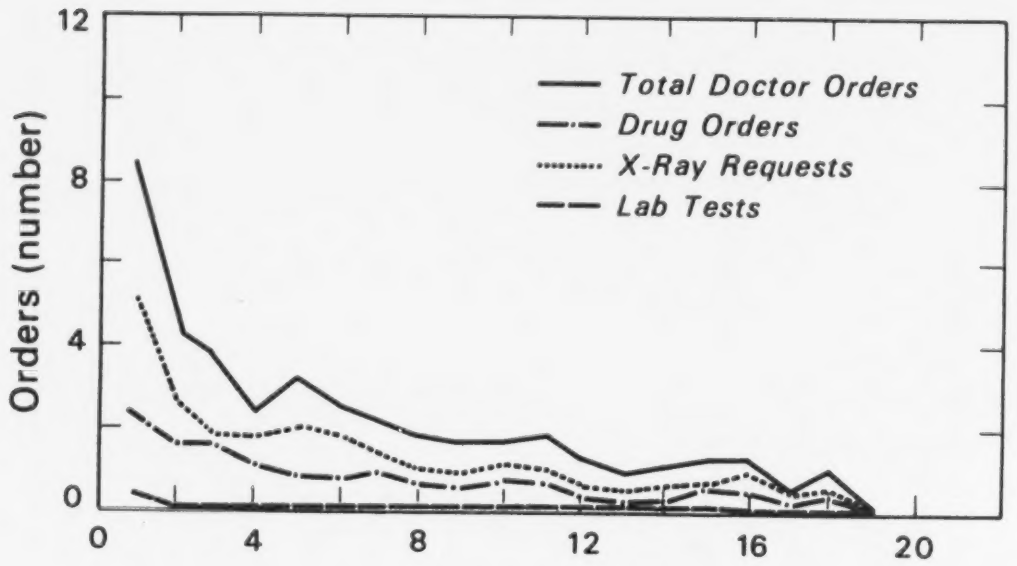

Figure 3. Distribution of doctors' laboratory, x-ray, drug (and total) orders by day of patient stay KFH-SF.

originated in the second and another 10% in the third. This is to say that 50% or more of the laboratory, x-ray and drug requests occurred within the first three days of a patient's stay. This relationship was true for the three facilities with little variation.

Although analyses have commenced on the isolation of process errors and the duration of process loops, little more can be said at this time than that errors and duration are affected by an interaction between volume of orders written and method of disseminating orders and retrieving results. Table 1 is an example of the duration analysis under way. The elapsed times (in hours) shown in each cell are products of interaction between general types of laboratory test and medical specialty.

Methods are under improvement to permit similar analyses of x-ray and drug ordering routines. Also, methods are being expanded to permit tests of effect of such variables as time of day, staff group differences by hospital location, etc.

ASSESSMENT OF THE UTILITY OF AN INFORMATION SYSTEM FOR STAFF

Group discussions and questionnaires were used to gauge staff's reaction to the manual communication system. Discussion groups were employed to

TABLE 1. ELAPSED TIME (IN HOURS) BETWEEN PHYSICIAN ORDER FOR ROUTINE LABORATORY TEST AND HIS RECEIPT OF RESULTS
KAISER FOUNDATION HOSPITAL - SAN FRANCISCO

Order	Medical	Medical/ Surgical	Surgical Emergency	Surgical Non-Emergency	Orthopedic	OB/GYN
Chemistry I	24.1	20.0	25.5	25.9	---	10.0
Chemistry II	24.7	22.2	25.8	25.3	---	24.4
Hematology	21.9	23.8	21.0	18.2	18.0	21.0
Urinalysis	19.2	19.6	15.0	12.0	15.0	15.0
Prothrombin Time	18.4	16.0	19.0	---	---	18.0
Bacteriology	87.6	92.0	72.8	68.6	65.6	79.3
Serology	30.4	21.0	27.0	24.0	---	21.0
Special Procedures	54.5	25.5	---	---	---	27.0

establish areas in which information exchange was of significant import to doctors and nurses. The questionnaire was prepared by extracting questions from analyses of discussion tapes; it was administered to medical and nursing staffs at large. Staff responded to the questionnaire in terms of the frequence with which a communication problem arose and the difficulty that event caused them.

Table 2 exemplifies the base for comparisons being prepared. This table arrays questionnaire responses by physicians and nurses regarding their views of

TABLE 2.–RESPONSES OF PHYSICIANS AND NURSES TO A QUESTIONNAIRE REGARDING INFORMATION PROBLEMS BY FUNCTIONAL AREAS

Most frequent and difficult problems					
Physicians			Nurses		
	Number	*Percent*		*Number*	*Percent*
Laboratory	422	51	Laboratory	203	33
Admitting	143	17	Admitting	98	16
X-Ray	124	15	Dietary	95	16
Staffing	101	12	X-Ray	90	15
Dietary	36	4	Staffing	87	14
Pharmacy	11	1	Pharmacy	38	6
Total	837	100%	Total	611	100%
Total responses =	7917			3876	
Responses viewed as being most frequent and creating the most difficult (Cell 1) =	837			611	
Percentage total =	11			16	

the ability of various ancillary services to receive and transmit important items of information. Physician and nurse responses were organized in terms of problems which occurred most frequently and were judged to present greatest difficulty. The services listed were those most intimately associated in the development of the medical data system. For both physicians and nurses, the

ordering of areas of concern is correlated with extent of staff group involvement with service areas from day to day.

Of larger import in the analysis of staff reaction to manual methods of exchanging information is the isolation of two variables believed to affect quality of evaluative information:

1. *"Extent of Use" of the information system.* Reaction of the staff in the department of medicine was compared to combined staffs of other services. This division is based on the determination that the department of medicine is the greatest user of the information system (more than 50% of all intermural messages, i.e., messages between subsystems, originate from medicine). Analyses revealed a significant difference between responses to questions about problems with the manual system, by staff in medicine and other hospital staff members. Both physicians and nurses in medicine see the greatest number of problems with the information system.

2. *"Remoteness of Staff" from the information system.* Remoteness, also thought to affect staff judgment of utility, is determined by the relative distance of a person's primary task from any activity under study. It was speculated that persons spending most of their time and having prime responsibility in settings where study events take place, would prove to differ in their reactions about systems problems from persons whose primary work assignment is elsewhere. An assertion was made that persons closest to, most immersed in and reliant on operations, express the strongest views about the importance of given problems. This assertion was tested by examining the responses of chiefs of service, staff physicians, house staff, and nurses. The latter two groups represent persons most proximal to and involved in operation of the information system in question. The former two groups are most remote because their principal work assignments are elsewhere. Findings supported the assertion. House staff and nurses were found to exhibit more extreme reactions to questions concerning information problems and had significantly more opinions concerning their import, than did staff physicians and chiefs of service, to that order.

[illegible] CRITERIA USED IN COST ANALYZING THE FOUR MAJOR ACTIVITIES CATEGORIES

Effort was made to isolate probable areas in which the new Medical Data System (MDS) impinges upon major activities categories. Hence, costs are separated as *Impact* and *Non-Impact*. Preliminary review of this analysis suggests that the economic effects of MDS may be somewhat less than

projected from gross review of time and effort devoted to hospital communication. Originally, the proportional range quoted for the cost of communication was 35-39% for the three study hospitals. Review of impact costs shows that only 23-27% of costs are assignable to impact communication commerce. Accuracy of the impact designations will be tested following MDS installation.

Development of an Evaluation Model. Results of the baseline evaluation suggest four major criterion categories for developing a medical information system evaluation model: (1) systems variables; (2) workgroup variables; (3) patient variables, and (4) interaction variables.

Only two issues related to evaluation model development will be discussed here. These are selected because of their central importance in planning and executing systems evaluation: (1) variable selectivity for specific outcome; (2) the import of interaction variables.

Variable selectivity. This term refers to establishment of specific outcomes affected by the operation of given variables. For example, the patient variable, *relative patient mobility*, is highly selective for the outcome, amount of doctor and nurse time and effort expended in patient care communication when patients are classed "bedfast." Bedfast patients on different medical specialty units generate unique patterns of staff response over time (by day of patient stay).

Lack of recognition that certain variables associate with specific outcomes is viewed as a major obstacle to the utilization of existing operational information in hospitals. Absence of this perspective also hinders needed agreement about what data to collect when planning an evaluation program, where concern is with measurement of operational effect. For example, diagnosis is an item of categorical information frequently used to evaluate a plethora of outcomes of hospital operation. Sense dictates that diagnosis is not a suitable criterion measure for all possible outcomes of patient care delivery. There are many *phenomenal relationships observable* in the hospital environment to which diagnosis as a measure has no relevance at all.

This is not to say that diagnosis is unimportant. Quite the contrary: in those phenomenal processes for which diagnosis is an outcome or a functional step in the process, it is of importance. In those processes where diagnosis occupies no such position it is worse than meaningless; if employed as a measure, it is misleading. The use of an inappropriate criterion introduces the risk of attaining statistically significant results by chance. Considering the frequency of use of diagnosis as a criterion, this eventuality does not seem remote. When

such false results are obtained, the operational person (the decision maker) who attempts to apply them is in jeopardy.

The above statements are best exemplified by a specific case. When we first attempted to identify variables that made a difference in the amount of time and effort expended by doctors and nurses on behalf of patients, the issue of diagnosis came up as a possible discriminator.

The capacity of diagnostic categories per se to differentiate amounts of time expended by staff in the hospital on behalf of patients was examined and proved unproductive. What did yield difference in staff time and effort expended upon hospitalized patients, was the absence of firm diagnoses. Uncertainty about the cause of patients' conditions, and a belief by staff (from various specialties) that the patient was in danger, showed great promise in accurately differentiating allocation of staff time. This experience did much to develop the perspective of variable selectivity. Although diagnosis is one important outcome of hospital resource utilization, not diagnosis but integral process events determine the specific outcome, *expenditure of staff time and effort in responding to patient needs.*

Interaction variables. Many hospital problems were found to result from intermural, rather than intramural processes. That is to say, the effects of problems are most critically felt across operating interfaces rather than within particular subsystems, where the seeds of problems are sown.

Interaction variables are of central importance, it seems, in perfecting an ability to solve systems problems by understanding and implementing pertinent system modifications. In effect, interaction variables provide basic analytic emphasis for mastering system problems that occur across the interface between functionally different, yet interrelated subsystems.

It is essential to understand, for example, that Different Day(s) of Patient Stay (represented by all patients in each Day of Stay) exert different, sequential work demands within a nursing unit, and on each service area making a contribution to particular care processes, e.g., ordering, filling, administering drugs. This organic interaction is further affected by the relative disposition toward and experience with the system of staff using resources and attempting to achieve outcomes. The aforementioned Extent of Use and Remoteness variables are thought to contribute significantly to the interaction process.

This discussion of evaluation has touched on the cited issues because of their importance for efficient production of useful results. In this view, one additional point will be made in closing. It is observed, on the basis of work to date, that analyses and tests of systems evaluation criteria proceed inefficiently

when conventional procedures are used. If, and when, simulatable models of medical operations are developed, evaluation results will become more accurate and readily available. In effect, the simulator must produce reasonable forecasts of pertinent medical operations in much shortened time spans. Simulation methods are the only available means for rapidly performing forecast - verification — modification — reforecast sequences without incurring unsupportable delays and staggering evaluation costs. The unstable state of affairs in the contemporary health field urgently requires that this effort start immediately.

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QUALITY OF DATA IN THE MEDICAL RECORD

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INTRODUCTION

Because a patient's medical record is maintained for many different purposes, the quality of data in the record cannot be evaluated without first considering the different roles played by the data.

PURPOSES OF DATA IN THE MEDICAL RECORD

Perhaps the most immediate and obvious purpose of medical data is in the clinical management of the patient. A medical record contains an account of what was found, what was thought, and what was done in the management of that patient. Yet the record is not always necessary for many of these activities, and it cannot contain an adequate description of many others. As long as the attending physician is aware of what is happening and appraises it well, he can take quite good care of a patient, regardless of the particular data that are formally inscribed in the record. Moreover, the intimate personal interchange that is sometimes called "bedside manner" is a crucial part of medical care, but its ingredients are difficult to describe briefly in words, and an account of the exchange is seldom recorded. Thus, the maintenance of a careful medical

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record is not always necessary for the immediate care of a patient, and the contents of the written record cannot alone be used as a complete index of the quality of care.

Because a doctor can function well in many individual cases without maintaining good written records, many doctors do not regard the record as a vital part of patient care. They may be perfunctory or sloppy in their record-keeping procedures, and resentful of efforts to impose rigorous standards or improvements. A doctor who can provide good medical care without a standardized formal record may believe that proposals for change and other types of attention to the records are an academic or administrative window dressing, increasing the complexity of patient care without really helping it.

This belief would be quite tenable if all the activities in a patient's medical lifetime always transpired between him and the same doctor, and if either the patient or the doctor could accurately remember all the detailed information that might have to be recalled on diverse medical occasions during that lifetime. Neither of these two premises can be assured in modern medical practice. The data produced today by complex technologic procedures are too numerous and diverse to be "stored" in any human mind; a patient often deals not with one doctor but with an array of consultants and paramedical personnel who must have a medium in which to exchange and communicate the information needed for medical care, as well as the information used in arranging payment for the care; and, finally, in a mobile society, the patient may move from his current source of medical care to another source that is geographically distant. For all these reasons, the modern medical record has become indispensable as an account of the patient's complete medical biography. Even though an attending physician can often manage current events well without having or creating a written report of them, the written report will contain information that is crucial at a later date, when the present has become the past.

A second major purpose for medical records is in analytic scientific investigation of clinical activities. The only way that doctors can validate our achievements in diagnosis and therapy is to find out what has been accomplished. This procedure requires clinical research in which the data of large numbers of patients are assembled, and the results of their clinical management are carefully appraised. This type of research is both difficult and unfashionable. It is difficult because the study of sick people requires much more effort, time, and intellectual versatility than the study of phenomena observable in a laboratory. A rat or a test tube is always available and

replaceable, keeps it appointments promptly, does not move out of town, makes no demands on the investigator, requires no explanations for informed consent, and can readily be destroyed to find out what has happened.

In addition to these difficulties in execution, research on the clinical course of patients is unfashionable because clinical science in the past two decades has been directed mainly toward problems in the mechanisms of disease, rather than problems in the management of patients. Large sums of money have been made available to support the study of disease mechanisms in molecules and enzymes, but not the study of clinical management in sick people. Consequently, the knowledgeable academic clinicians who might perform the research have not been encouraged to do so. They either leave the academic world and forsake investigative work, or they divert their clinical talents into doing the laboratory activities that are more readily supported financially and rewarded academically.

As a result of these fashions in "basic research", and the resultant apathy for truly clinical investigation, the quality of medical records has paradoxically declined during an era of increasing need for good medical records and for research using medical records. The university medical center often performs an elaborate technologic work-up of the biochemical and physiologic derangements in a patient's disease, and therapy may be instituted according to certain physiologic rationales; but the patient's record will not include a careful description of his personal and clinical properties, and almost no one bothers to find out what happened afterward, when the patient leaves academia and returns to the referring physician.

Another current intellectual fashion is to talk about "community medicine" as an important problem mainly in the social or economic aspects of medicine. But medicine in the community is also an important problem in the science of clinical therapy. Throughout the long history of medicine, dating back to Hippocrates, every useless or harmful treatment has been accompanied by a physiologic rationale. Many of these treatments endured for centuries until enough observational experience was organized to demonstrate that, despite the approval of physiologists, the therapy had no clinical value. For example, blood-letting was a daily staple of medical therapy for 2000 years until Pierre Louis in 1835 demonstrated its worthlessness from data collected in a careful survey of patients' medical records.[1]

The way to evaluate treatment is to see what it accomplishes in patients, and the observational evidence will come both from careful medical records and from an extended follow-up after the patient leaves the hospital and

returns to the community. "Community medicine", therefore, should include not merely the delivery of health services, but also the acquisition of scientific information with which to determine the value of the services, and to make future decisions about which services are worth delivering.

In addition to these roles in clinical management and research, the data of medical records are used administratively for many purposes – among them the arrangement of payment for medical services. Furthermore, the medical record is a legal document, particularly for questions of malpractice. The records are also used administratively for inspection by committees that confer hospital accreditation. These inspections, however, are often so superficial that they may encourage rather than prevent poor practices in record keeping. For example, the accreditation committee usually demands that a "review of systems" be part of the patient's record, but does not check whether the review is complete or accurate – as long as it is there. To maintain accreditation, medical institutions will therefore arrange for a "review of systems" to be entered in the record. Since no one checks the quality of this review, it is often so perfunctory that it is worthless for the care of the patient, worthless for scientific research, and worthless for any real administrative or legal purpose – but it achieves the goal of being present for approval by the accreditation committee. In this way, a demand that was established to promote good patient care becomes converted into a procedure that perpetuates defective medical records.

These administrative and legal functions of medical records are really of minor clinical importance, however, and the rest of this discussion will be concerned with the major roles of medical records in direct management of patients and in scientific investigation of the clinical managerial activities.

ORGANIZATION OF DATA IN THE RECORD

Since the medical record is really a catalog of data, let us consider the way the catalog is organized at the usual university medical center that helps set and teach standards of medical practice. The conventional arrangement of the record is based on the sources and chronology of data. The history and physical examinations performed by the attending doctors are usually kept together in a specific section of the record, as are the radiographic reports and various other consultative procedures. The results of laboratory tests are assembled

separately, and the nurses' notes and social workers' notes are also given their segregated locations in the record.

Within the notes supplied by each of these sources, the arrangement is chronologic. The attending physicians begin with an admission history and physical examination, followed by an "impression" that lists a diagnosis of the patient's disease, followed by a sequential array of "progress notes." The admission x-rays in the radiographic section are followed by reports of subsequent x-rays; the admission laboratory data, by the subsequent laboratory data; the admission nurses' notes, by subsequent nurses' notes; and so on. In an outpatient medical record, this same chronologic sequence is maintained, although somewhat iess compartmentalized for the fewer people who add different types of information.

This conventional organization of the medical record has been vigorously criticized by Weed[2] with the arguments that data should be assembled in the record according to their focus, rather than their source; and that the focus should be a patient's actual problems, rather than arbitrary designations of diagnostic names of diseases. For example, the diagnosis of myocardial infarction identifies a disease, but does not tell us whether a patient is still having chest pain or shortness of breath, whether he is calm or anxious, and whether his family is being bankrupted by the high costs of the hospitalization. Dr. Weed has been an eloquent spokesman for what he calls the "problem-oriented" medical record, in which series of problems, enumerated when the patient is first encountered, are then used as the focus of referral for the subsequent notes, which are added chronologically, but arranged numerically according to the old or new problems to which they refer.

Dr. Weed's points are well taken and cogent; and the "problem-oriented record" has become increasingly popular at university centers among medical house staff who find this approach useful for arranging information about the many tests and consultations that occur in academia. In group practices where a patient may be seen by several different physicians, such records are also useful for the intercommunication with which the successive doctors must quickly determine the status of each of the patient's difficulties.

Although the problem-oriented approach provides an improved method of cataloguing the data in medical records, it obviously does not deal with the more basic issues of quality in the data that become catalogued, nor does it deal with the general issues of validation for the diagnostic and therapeutic decisions that doctors make in managing the patient's problems. The

problem-oriented record, in analogy, offers us a better way of arranging the books in our library, but it does not answer our basic questions about which books are worthwhile or obsolete, and whether we use the books effectively. If we are really concerned with the quality of data in medical records, we must contemplate issues far more profound than the questions of how to catalog the data.

TRADITIONAL CONTENTS

Let us consider the kind of information that becomes entered into a medical record, regardless of who enters it or where it is put. One type of data can be called *demographic* – describing the patient's personal properties (such as age, race, sex) and his environment (such as occupation and birthplace). Another type of data is *clinical*. It contains the patient's description of his symptoms and the way they developed, and the physical signs that are found by the doctor examining the patient's body. A third type of data can be called *paraclinical*. It contains the results of examinations performed away from the bedside upon substances that are removed or derived from the patient. Such data include the results of roentgenography, biopsy, cytologic study, various types of endoscopic examination or catheterization, electrophysiologic tracings, and laboratory tests. A fourth distinct type of data can be called *therapeutic*. It contains descriptions of the different diets, drugs, anesthetics, surgical operations, or other maneuvers that are used to administer therapy. A fifth category of data contains *miscellaneous* information, and would include such administrative items as consent forms, insurance records, and so on.

This is the array of information that medical students, house officers, nurses and other people have been taught to obtain and to write into medical records. Computer programs have been or are now being developed to obviate the necessity for writing, so that the data can be entered directly into a computer medium rather than on a printed page; and a number of programs have been developed for the computer to act as the "interviewer" that obtains certain data directly. Unfortunately, the computer programs are based on accepting the current status quo and automating it, instead of recognizing the many deficiencies that call for major improvement rather than mere automation.

DEFECTS IN TRADITIONAL CONTENTS

The demographic and clinical information that we currently enter in medical records is inadequate because it omits many important details. The traditional ideas about the contents of medical records were established many years ago in the era when a clinician's prime scientific challenge was merely to arrive at a correct diagnosis. Although these challenges have now been expanded into such new scientific activities as genetics and therapy,[3] the traditional contents of the record have not been expanded to include many of the details that are needed if the data are to be used scientifically in the analysis of genetic phenomena, and in the careful, quantified appraisal of therapy.

Demographic data about *race* have been hopelessly imprecise. As long as a patient appears to have any Negro characteristics, he is recorded as being *Negro* even if he has three white grandparents, and seven white great-grandparents. Although we carefully record such physical items as the position of the trachea or the respiratory rate, we do not ordinarily record the color of a patient's eyes, the color of his hair, or the existence or distribution of baldness.

In the patient's clinical history, we often record the "chief complaint", but we do not enter the "iatrotropic stimulus" that made him seek medical attention at the time he sought it. For example, a patient may have the chief complaint of chest pain for nine months, but the iatrotropic stimulus may have been the recent death of a sibling due to a heart attack. In recording "severity of pain", we usually accept the patient's description of his pain as being mild, moderately severe, or very severe – but this subjective estimation is not made meaningful by a correlated comparison with the severity of previous episodes of the same pain or other pains, and we do not regularly delineate the functional severity of the pain by noting whether it impairs such routine activities as eating, working, or sleeping.

If two symptoms have begun at about the same time in the past, they are usually noted as essentially contemporaneous, without an effort made to distinguish which symptom came first in the sequence. If a manifestation is said to have an insidious onset, attempts are seldom made to determine an upper limit of time for its duration by reference to its presence or absence at important previous dates in the patient's life, such as birthdays, anniversaries, or national holidays. We often talk about "early detection" of cancer, but we make no real effort to assess how long the detected cancer has been present or

might have been present, because we do not regularly compare the antecedent results of previous x-rays, endoscopic observations, palpations, or other examinations of the region where the cancer has been found. When a patient states that in the past he has had such diseases as rheumatic fever, pneumonia, or appendicitis, the gullible medical historian may make no effort to ask enough about the details of those illnesses to enable a decision about whether the alleged diseases were truly present. Despite more or less care in taking a history of the patient's symptoms, we often get few or no specific data about his functional state in regard to being able to work, feed himself, make love, or engage in other acts of daily living.

The effort to discern what has been accomplished by treatment is often thwarted by the incompleteness of details in progress notes or outpatient notes, which may not describe the particular target in the desired therapeutic response. Suppose, for example, that a patient has received palliative treatment for cancer. We might like to know what has happened to his pain or his ability to function in daily life – but we can't find it in his medical record. In surgical clinics, the notes will provide a description of his wound; in radiotherapy clinics, we are told about the size of the x-ray portals and condition of the skin; in chemotherapy clinics, we learn about the white blood count and the magnitude of whatever enzyme is under study; in internal medicine or pediatric clinics, we are told about the serum and urinary electrolytes. But nobody tells us whether the patient walked into the clinic or came by wheelchair; whether he is comfortable or miserable; and whether he is really alive and vibrant, or surviving by vegetating.

In the example just cited, follow-up data were available, but incomplete. At many medical centers today, of course, there might be no follow-up data at all. As noted earlier, the patient who is discharged from a university hospital is also often discharged from everyone's concern, and if he does not return at a future date, or if there is no particular registry group to get further data about him, the medical record will contain nothing about his future course.

There is an additional type of information – called decisional data – that is also crucial in the evaluation of therapy, and that is also regularly omitted from medical records, because no one has made a point of giving the information a name, and insisting that it be recorded.[4] For example, physicians seldom indicate the specific reasons they have used for starting, stopping, or altering treatment. Thus, we may be unable to find out why an "inoperable" patient was deemed inoperable; or why one antibiotic was stopped and replaced by another; or why diuretics were added to the regimen of a patient receiving

digitalis. A second type of decision that is regularly omitted from medical records is the attribution of symptoms in a patient who has two or more co-morbid diseases that can cause the same symptom. Thus, when a patient with rectal bleeding is found to have hemorrhoids *and* diverticula *and* sigmoid carcinoma, no attempt is usually made to state which one of these lesions, or all three or none, was believed to be the cause of the bleeding.

Finally, just as we fail to cite the iatrotropic stimulus as the reason for the decision that makes a patient seek medical attention, we also fail to cite the reasons for his decisions to reject the diagnostic or therapeutic proposals that may be offered him. As a result of these and other omissions in data, the evaluation of therapy becomes chaotic. A patient with cancer, for example, can be "inoperable" for at least three different decisional reasons. The first reason is that the patient died before any therapeutic decisions were made; the second is that the doctor decided the disease was too widespread; and the third alternative is that the doctor believed the patient was "operable" and offered to operate, but the patient refused. Here are three distinctly different patients, with three disparate courses and outcomes of disease, all lumped together under the name of "inoperable" – and yet clinicians wonder why so many statistical controversies[5] have developed about the results of treatment for cancer.

These phenomena are generally neglected in medical data today not because doctors are foolish, imperceptive, or dehumanized. A good practicing clinician is usually aware of all these things, and he weighs them carefully when he does his clinical reasoning. But he has been systematically taught to call the activity "clinical judgment",[3] to regard it as a form of art rather than a necessity of science, and to reserve the medical record for more allegedly "scientific" entries, such as the results of laboratory tests. The importance of clinical data in evaluating management of patients has been obscured by the scientific obsession with studying mechanisms of disease, and by another scientific obsession which holds that the information obtained from conversation with a patient is relatively worthless in comparison to the data obtained by examining his x-rays, blood, urine, or feces.

PROBLEMS IN VALIDATION

One of the main causes of the latter problem is not that clinical data are inherently unscientific, but that clinical investigators have made so few efforts

to improve the scientific state of the data. In dealing with laboratory data, we usually work with instruments that have been calibrated, and with chemical tests that have been standardized. But in clinical data, our main observational apparatus is a piece of human equipment called a physician, and this apparatus is seldom checked or tested. Although suitable methods are available, or could be developed, for studying and reducing the types of observer variability that occur when doctors examine patients, the activity is still scientifically primitive. It is omitted from most research projects in which it is necessary; it is not included in contemporary medical education, with or without the so-called "new curricula;" and it is not being used to validate the data now being enthusiastically stored in computers.

What is needed [3] is to check the reliability of the patient's perception and any motives he may have for deluding himself or his physicians; to determine whether the doctor and patient have communicated with one another in terms that are comprehensible to both, and precise enough to supply the details needed in scientific description; to determine whether the doctor has satisfactory sensory perception, and to eliminate the biases that arise when he is told, before he examines a crucial region, what has been found in previous examinations; to insist that the doctor's observations contain enough description of the elements of evidence, rather than his conclusions about the evidence; and to demand that the interpretation of the observations be performed with rigorous, specified criteria.

In his immortal remarks about the management of human illness, Francis Peabody said that the secret of patient care is in caring for the patient. Similarly, the secret of scientific clinical examination is in examining the patient scientifically. We cannot escape the need for using our human talents in this work, but we can make the resultant data much more reliable if doctors will pay primary scientific attention to our own methods of examination, rather than to laboratory techniques and extrinsically automated procedures that get precise, quantified, reproducible answers to the wrong questions. The greatest need of clinicians today is not for more technologic innovation, but for an intellectual reorientation that will lead us to develop greater objectivity, precision, and specification in our examining procedures, and that will be accompanied by the establishment of rigorous criteria for each of the intellectual maneuvers used in transforming the observed evidence into the interpreted conclusions. Without these improvements in the methods of acquiring data, in the choice of data to be acquired, and in the intellectual

algorithms used to interpret the data – the results will remain scientifically inadequate for the needs of medical practice.

The main content of this symposium is devoted to the splendid new technologic systems that are available for storing and processing medical data. But every computer expert knows the maxim about "garbage-in-garbage-out." If we are to avoid creating an elaborate, expensive, intricate set of medical systems for processing garbage, there must be at least equal, and perhaps paramount, attention to the development of procedures for refining the garbage and extracting the fruits before the data reach the computers. This activity will require careful clinical thought rather than technologic hardware; clinical algorithms and clinical criteria rather than cathode ray tubes, electronic pens, and typewriter terminals; and an acceptance of the scientific challenge that we must collect and analyze medical data for the purpose of preventing or managing the ailments of man. A computer system that has no defined clinical purpose, and that merely stores data in an arbitrary manner, however elegant, can provide neither quality in the data nor quality in the scientific clinical goals for which the data are used. If we create these basic improvements in medical data while we use the new technology, the ultimate results can be magnificent. Otherwise, we may spend a great deal of money, time, and energy merely to automate an unsatisfactory and highly defective status quo.

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TERMINOLOGY AND CONTENT OF THE MEDICAL RECORD

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INTRODUCTION

The problems of medical documentation are disturbing to practice, administration and related services. The situation is puzzling because the difficulties occur in the midst of medicine's greatest advancement. The observations of Brooke are significant:[1] Consider the reams, quires, and bound volumes of medical records lying tier upon loaded tier in hospital after hospital throughout the country; consider the devotion of those who have industriously recorded the history of illnesses and examinations – usually laboriously in longhand like any practitioner of the 19th century; and then consider the monumental library of human casualty. Then pose the question – to what end?

Any person who attempts a serious but honest piece of clinical research will recognize the limitations and frustrations of medical documentation. Indeed, he would gladly join colleagues in protest with proposals to resolve this dilemma of medical documentation and communication at almost any cost. Conformists who cling to the rule that requires a complete medical record on every patient may disagree despite demands of patients for the rendering of direct and timely medical services. There is an immediate and sensible reply: There naturally must be a record of the patient's illness for future reference. But, that reference should be valuable only for the future management of the individual case. Obviously, a data base application could be valuable, but this is somewhat beyond the realm for practical consideration at the present time.

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Three avenues are open for the study of methods to improve medical documentation: focus attention at the "grassroots" of medicine to reveal the basic difficulties of data recording; cultivate sophisticated technologies and computer hardware in the higher reaches of engineering science for assistance in medical documentation; or encourage a meeting of the minds midway, through a problem-oriented approach.

Pertinent questions are posed as the needs for the improvement of data recording are emphasized: What are the purposes of the medical record? What should be the size or coverage of the medical record? What is the value of the medical record in terms of human effort and financial expenditure involved in data gathering and recording? What type of computer assistance in medical documentation is contemplated?

TOOLS FOR DATA GATHERING AND RECORDING

The American Medical Association is concerned with the development of tools for data gathering and recording for manual reference and computer input. The mechanisms include regularization of terminology and stylization of the data. The source materials for the program encompass medical textbooks, the current literature, and hospital clinical records or case reports.[2] The observations and considerations are summarized as follows.

Approximately 24,000 different terms are used in medical publications for the naming of 3,700 to 3,800 specific diseases. The remainder includes 10,000 synonyms or eponyms and approximately 2,000 descriptors usually reserved for the designation of manifestations. The latter are sometimes employed for diagnosis; for example, the descriptor "hemoptysis" may appear when the cause is unknown. In addition, 150,000 different descriptors, symbols, and abbreviations are employed for signs, symptoms, and laboratory tests when approximately 18,000 to 23,000 would suffice.

The group of descriptors presently considered sufficient for the description of all diseases is undergoing manual and computer analysis to determine the frequency of usage for diseases appearing under different classifications or systems of the body. Preliminary studies suggest that a greater number of descriptors may be required for the description of heart diseases than for pulmonary conditions. This is attributed tentatively to the fact that multiple etiologic factors, mechanisms, and laboratory tests must be recognized in the

study and treatment of heart diseases and disturbances. In pathology, the number of descriptors may be relatively limited since descriptions pertain to basic observations such as cell infiltration, inflammation, proliferation, fibrosis, sclerosis, contracture, necrosis, etc. over and over again.

The arrangement of data in the medical textbooks and journals varies somewhat from edition to edition and from presentation to presentation, even in contributions by the same author of a given publication. For example, "patchwork" introductions appear to be the result of expediency, as the only practical means to avoid printing an entirely new page or chapter. Thus, symptoms appear in paragraphs previously designated for physical signs; similarly, items that should be contained in sections on pathology are presented under laboratory headings, course, or complications. The penalty in certain instances is duplication with conflict.

The vocabulary of medical records is variable, involved, and extensive, thus exhibiting the features of medical textbooks and the current literature with a quantum of barbarisms, jargon, colloquialisms, slang, cant, colorful sayings, self-generated symbols and abbreviations – "intern language." These superimposed complexities of terminology are sometimes identified geographically with medical schools, hospital centers, service hospitals, and local "chit chat" along the highways and byways of practice.

The organization of data in medical records is rarely systematized except in presentations by medical students and "new" interns serving under the direct supervision of dedicated chiefs of staff. The records in research centers tend to be complete in special areas but disorganized or sketchy in others, an understandable situation since attentions are focused on particular problems under investigation. In service hospitals, the records are essentially running accounts of the illness with loose-self attachments of laboratory reports and charts. This jumbling together of pages sometimes suggests the possibility that "memory" of antecedent events becomes the better part of practice in preference to laborious and time-consuming efforts for reference and mind refreshment.

The effective preparation of satisfactory abstracts of clinical records depends on the clarity of the source material; i.e., the data in the main or original medical record. In some instances, only five or ten significant items can be elicited from a medical record, while 35 to 50 items are easily identified in the record of an identical case. The situations in abstracting are almost the same when journal articles are presented precisely, as compared with those appearing without serious attention to clarification and organization of the content.

The adaptation of computer technology in practice must be concerned with the customs of 200,000 physicians serving independently or in 7,000 hospitals and clinics. Indeed, customs of manual documentation are so completely ingrained that changes of procedure could become bewildering, impractical, and even less effective than those now used. It appears logical, pending clarification of the entire matter of documentation and communication, to proceed conservatively, and thus accept present medical records on face value by using a system of abstracting to bridge the gap of difficulties between manual recording and computer operation.

Computer assistance: The computer is sometimes visualized as a magical instrument, quite capable of resolving the difficulties of medical documentation. But enthusiasm wanes with the discovery that the computer is merely a "bookkeeper" with "errand boy" capabilities. Indeed the computer can make crooked things straight but, contrarily, it can make straight things crooked. The cruelest cut of all, however, would be to accuse the computer of wrongdoing when the basic cause of failure is the human equation itself. Thus, critical data with proper organization are essential for effective computer operation.

THE MEDICAL RECORD FORM (MRF)

The MRF* is patterned after the "worksheets" used successfully for the development of *Current Medical Information and Terminology* (CMIT).** The goals are as follows: To simplify and standardize the preparation of a medical record summary; to provide for the main medical record a systematized medical summary; to facilitate reference to significant information and expedite communication; and to provide satisfactory computer input.

*Samples of MRF available on request.
**Published by American Medical Association, Chicago, 1969.

Accordingly, MRF may become part and parcel of the medical record, thus offering conveniences for manual reference, and, in a related role, serve for computer processing and storage of medical record. The format is composed of a "face sheet" assembly with a cover and two identical outside detachable leaves for administrative purposes; directions are included in the form. The body of MRF is composed of eight pages. Each page is numbered and divided into sections; each section is designated by title, and is reserved for specific items such as physical signs, laboratory, etc. The lines of each page accommodate 5 to 8 words or 55 to 60 characters. Accordingly, each section constitutes a paragraph, and each line is classified as a "level". The pages of MRF are bound together and may be reversed for convenient writing and typing.

Methodology for MRF. The use of MRF is based on sequential procedures: scanning the entire medical record for significant information; identification of significant data in the body of the record by mark-sense lines; identifying significant items in laboratory reports and charts; transferring subject items to specified sections of MRF; followed by editorial revision and arrangements of the data.

Regularization of terminology for MRF. Preferred names and descriptors of diseases and manifestations of the medical record should be used, but "intern language" must be avoided. The reasons for selection of terms are three: To reduce the volume of medical records; to avoid misinterpretation of the data; and when the data are computerized, to expedite automated searching, indexing, matching, and retrieval. The author's own words are given preference but it may be advisable to consult CMIT for the preferred use of terms as between: gangrene, necrosis or necrobiosis; hypertrophy, enlargement or hyperplasia; albuminuria or proteinuria; exudate or inflammation; stasis or stagnation; squint or strabismus; squamous or scaly; eructation, retching or belching; vomiting or emesis; Parkinson's disease, paralysis agitans or parkinsonism.

Stylization of MRF. The syle of MRF is patterned after the composition of CMIT, using "headlines" and a journalistic type of presentation. Thus, "what" refers to the complaint, "where" to the location, "kind" to the type or degree of presentation, "when" to the occurrence or onset, and "course" to indicate succeeding events as prognosis, results of treatment, or the occurrence of unfavorable situations. Accordingly, nouns assume priority and appear first as in a clause to express "what"; while adjectives or adverbs serve secondarily as qualifiers; verbs, conjunctions and free text are rarely employed except to clarify the data.

Punctuation of MRF. The punctuation of MRF follows the system of CMIT. The comma separates or brings together related clauses, descriptors, or units of expression; the semicolon separates a series of clauses, e.g., "heart, pain, paroxysmal", and "cough, hacking, loose"; the colon introduces a series of clauses; a period closes a final clause or a set of clauses.

Arrangement of items in MRF. Systematic listings and arrangements of MRF facilitate manual reference, computerization and automatic retrieval. Thus, the most significant complaints and findings of the medical record are listed in MRF under proper headings, and in order of importance.

Numbers, percentages, and numerical ranges of MRF. Numbers in CMIT have been reduced to the minimum, for the following reasons. The computer "looks upon" each different number as a new word and, under the circumstances, a significant relationship to a given item could be "lost". This is demonstrated in the key-word-in-context of CMIT when "WBC 20,000" appears in one context, and in another as "21,000 WBC". A similar situation would occur if incorrect spelling were used such as absces instead of abscess. The descriptors "increased" or "decreased" and "high" or "sustained" are generally more meaningful in computer analysis than a series of numbers that represent relatively small changes. An exception to this manner of listing would occur when WBC is definitely significant or the fever is high; thus "WBC increased 60,000", and "fever high 105 F." should be used.

Example of completed MRF based on the methodology of CMIT. The abstract of 200 words was prepared from an excellent but lengthy medical record of 72 pages. The following arrangements are noted: the data are stylized with the primary use of nouns, adjectives, and adverbs according to methodology of CMIT; thus, specific punctuation and organization of data are stressed; dates and initials of examiners (ALG, SND, JKL) have been added to indicate the sequential events and studies.

et: (History or etiology of the disease): social history, family history, occupation, previous illnesses: anthracite coal miner, hard rock driller, tunnel mining 10 years; age 45; wife, 5 children;ample support through laborious work; bronchitis, attacks 2-3 yearly, 10 years; cigarette smoking 1-2 packs daily 5 years; ALG, 6/2/67.

SM: cough 15 years; dyspnea exertional, progressive 6 years; disability serious 3 months, aggravated by colds of head, chest; ALG, 6/2/67.

sg: cyanosis of lips; clubbing of fingers, chest A-P increased; expiratory sounds right apex prolonged; wheezing rales throughout chest; heart rate regular, sounds distant; blood pressure systolic normal, diastolic elevated; fever

high 103 F, ALG, 6/2/67. Course: tobacco smoking stopped; epinephrine, tetracycline, treatment of bronchial spasm, infection effective; diaphragmatic exercises with IPPB effective; rales decreased, ALG, 6/14/67; prognosis guardedly favorable with regulated health regimen, discontinuance of occupation, ALG, 6/23/67; discharge 6/26/67. Final diagnosis: pneumoconiosis; emphysema, pulmonary, ALG, 6/6/67.

cm: pulmonary emphysema, ALG, 6/23/67.

lb: sputum: mucoid, black; specific organisms absent; cultures negative; copied ALG, 6/4/67; repeated negative, ALG, 6/9/67. Function: vital capacity reduced, copied ALG, 6/9/67, increased copied ALG, 7/1/67; residual volume increased, copied SND, 6/14/67.

xr: lung radiolucency increased JNC; small to massive nodulations of lungs; diaphragm irregular outline, depressed JKL, 6/5/67.

An MRF program requires mark-sensing of significant data in the main medical record by the physician in charge of the case followed with documentation by a medical record librarian, an office nurse or a technical assistant with major English education. Thus, participation in MRF use is comparable to the "team" activities of CMIT staff. The time required for the preparation of MRF is directly related to the handicaps of complex terminology, poor penmanship, and faulty arrangements of the medical record. Medical students working at the AMA, accustomed to the techniques for CMIT, are able to scan and mark-sense an average medical record in about 10 minutes and transpose the data in 2-3 minutes.

The companion use of *Current Medical Information and Terminology* (CMIT), and *Current Procedural Terminology* (CPT) for MRF could be helpful. Accordingly, CMIT would serve as a remembrancer of medical knowledge to exemplify the value of preferred terms and random codes for the designation of diseases, and the importance of precise descriptors for the description of manifestations. In addition, CMIT would illustrate the advantages of stylized presentations and systematic format. CPT could also serve helpfully as a guide for the selection of diagnostic and procedural terms and sequential codes for recording and communication.

The medical record has grown like Topsy, reflecting extreme variations in the selection and description of content for reference and communication. Not even the most skilled and dedicated physician is able at all times to make a clear distinction between substance and related influences in a given disease situation, between what is basic and what is merely speculative. Indeed, some

items in a medical examination may not be worth recording or communicating. Moreover, in an age when information storage and retrieval remains an unrefined concept of advanced technology, there is still time to consider the questions, whether some information, once stored, ought to be retrieved, what is necessary to know, what is nice to know. Perhaps as an antidote against the future, one might recall that Sir Ernest Gowers in his *Plain Words* quoted an ancient scroll, bearing a letter written by a Minister of Finance to a civil servant. It is a model of pertinency and finality: "Apollonius to Zeno, greeting. You did right to send the chickpeas to Memphis, Farewell."[3]

The predicaments of medical recording are not easily resolved, but computer technology and hardware can be helpful: the cathode ray tube with light pencil; matrices; voice transmission; devices for graphic communication; programs for dialogue; optical uptake instruments; checklists; philosophical proposals for clarifying the mechanisms of illness for computer analysis in depth. The knotty problem is *quality* and *dependability* of input that must originate personally and professionally in the areas of practice.

Practical, logical, and sophisticated programs for acquiring information are under investigation in various centers within the United States, as in multiphasic screening and the study of subtle nuances of symptom complexes including behavior and the effects of co-morbid ailments.[4,5] Similarly, proposals for problem-oriented medical records offer great possibilities for the structuring of medical records. Self-education through references to a type of data base as CMIT could serve as a library of medical information for teaching, thus indirectly influence the quality of medical records.[6,7] But, questions are posed in medicine *per se* on the feasibility of computerization of the medical record, arising especially from difference in goals or purposes. Pending clear and well- defined answers, initial steps should be simple, and limited to the documentation of significant items with the incorporation of multiphasic data. The sample MRF case of pneumoconiosis could serve as a guiding step for implementation.

In a conservative sense, computer capacity is a vital issue in the storage and handling of medical information. Computers are not boundless instruments for the storage of "complete" medical records, i.e., for negative as well as positive data. Indeed, the computer could be as cramped for space as present-day medical record libraries, while the pipe lines of communication are choked with irrelevant material. Thus, automation might become a snare and delusion! Apart from capacity limitations, excessive costs for search and retrieval rear their ugly heads. Accordingly, selective data based on fundamental research

with preciseness of description are essential for economical and manageable computer processing.

First things first: This forceful dictum seems applicable in the approach to resolve the perplexities of documentation; i.e., the purposes and content of the medical records should be determined first. The dangers of misalignment or "jumping overboard" into the realm of computer technology are real and should be avoided. Indeed, critical and basic planning is definitely indicated; otherwise, engineering knowledge and hardware could outstrip the admittedly drab but necessary chores of data recording at the level of practice *per se*. This is not to be skeptical of automation in any sense, but rather to indicate that simple steps in documentation must begin in the actual fields of practice.

Second things next: After techniques are perfected for data gathering and recording in practice, development of a computerized data base should become the ongoing goal. Incentive for this concept is taken from Osler's day, before the advent of biomedical technology, when the material from clinics, laboratories, and hospitals served basically in medical education, writing and reporting. The prospects for gaining clinical information from the experience of practice are as promising as the opportunity has been for developing CMIT from the base of standard textbooks of medicine and the current literature.

The volume of the medical record can be resolved through the selection and use of terms that convey meaning exactly. Accordingly, preciseness and specificity of terms is a basic requirement of medical documentation. When these are practiced consistently, the size of the medical record, excluding graphs, charts, etc., may be reduced by 60 to 80 percent or more. At that point, the medical record may fall within the framework of computerization and data base utilization.[8]

Promise for improved medical abstracting and documentation is revealed by experiences of medical students who have served at AMA for the development of CMIT and used MRF for abstracting medical records. The majority have returned to their hospitals for training as clinical clerks with an improved facility for preparing medical histories, as noted repeatedly by teachers and chiefs of service. This may suggest clues for increasing the quality of clinical documentation in hospitals and, indeed, emphasize possibilities for judging the effectiveness of education and professional services. The accomplishments of physicians and assistants could be somewhat comparable to the abilities of *Readers Digest* to compose lengthy articles and even books into lucid and delightful presentations.

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LARGE VERSUS SMALL
SINGLE VERSUS MULTIPLE COMPUTERS

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INTRODUCTION

Our past experiences led us to identify four broad classes of user of computerized services in health service delivery.[1]

We found that one quarter of the users are in hospitals ranging in bed capacity from 250 to 1000 or more. One quarter are in state or city health department programs, either urban or rural. Another quarter are concerned with employee health screening or group practice programs. The final quarter are those in various aspects of research, primarily epidemiologic or intervention studies. At the present, individual physicians show interest in computer services but only a few have reached the point of using them.

In looking at this "market", it becomes clear that not all users can or should be serviced in the same way. It also becomes clear that computer operating costs and the conveniences that can be provided are dependent upon the combination of the input, output, and mode of equipment utilization at the user and the processing sites and at the interfaces between the two sites.

The choice of a large, small, single, or multiple processor can be defended by one's own requirements in any specific situation.

This presentation will center on how the four types of user we encountered were accommodated by small processors by minimally changing the mode of operation of the computer center. It is intended for the group concerned with

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providing services (or doing research and development) for those concerned with health service delivery.

Our model for discussion is an automated electrocardiographic information system.[2,3] We confirmed that the system is adequate as a general automated information system model by trials of portions of the methods for spirographic,[4] electroencephalographic,[5] and phonocardiographic[6] information systems. We will confine the major part of the discussion to the portion of the system dealing with computer processing.

EDUCATIONAL REQUIREMENT

To orderly implement a system and select a processor we must first describe the objective (and determine that computerization is reasonable); second, designate procedures for evaluating whether we have reached, or are reaching, the objective; third, detail the mode and logical time scale of development in an effort to reach the objectives.

The most crucial lesson learned from 12 years of experience is that a system is relevant in an environment only after education and training of the prospective researcher, developer, and user. Each of these groups must understand thoroughly its objectives and the system's users must understand its benefits and limitations. Cost, reliability, and quality all appear to be secondary to knowledge about the system. As in his manipulation of drugs, the physician with appropriate knowledge can make up for shortcomings in reliability and quality. Thus, to aid the physician, machine systems do not have to be perfect if he is given appropriate education.

We judged most significant in the educational process that aspect which allowed the researcher, developer, or user to fully comprehend *his limited* objective and to accept the role as an interface with the system and with other groups in the system, each group necessarily having other objectives.

OBJECTIVES

The model system under discussion was developed by a mission oriented laboratory.* It was organized to enable the government to have in-house expertise in the application of automated techniques to heart disease control.

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The laboratory was given the task of researching, developing, validating, and in effect "marketing" a system. Our project was the Heart Disease Control Program's translation of those directives in congressional legislation that were intended to bring into public use techniques that could in some measure counteract the disease that kills a large segment of our population. Understanding and keeping that mission foremost was a most difficult aspect of our education. Our assigned role was a substantial directive element in our selection of a specific processor. We knew that to fulfill our mission we had to deal with low cost systems in multiple areas of the country.

Parenthetically, it appears to us that failure to keep the major objectives in mind over protracted periods explains most failures in computer selection and usage in the medical field. A great many exciting, fascinating developments in the computer field can rapidly distract our attention away from the mission itself. For example, we had to be constantly aware during our project that we should not become expert in large, small, single purpose, or multiple processors at the expense of our medical mission.

The time scale of a project has an important influence on the choice of computers for research and development. After two years of planning, Dr. Robert Grant, our major Medical consultant, initially estimated that our project would reach completion at two years; the laboratory director (C.A.C.) estimated three years; the head of the sponsor agency, Dr. Arthur Rikli, estimated five years. The project is still incomplete at nearly ten years. Computer manufacturers bring computers out rather frequently. During our model project's nine and a half years, Control Data Corporation developed, among others, the 160, the 160A, and the 3000 and 6000 series. IBM made available the 650, 704, 7090 and 360-50 models. Digital Equipment Corporation brought out several PDP series. Most of these (or similar machines) could have done the job required. We could have switched from any one to another to take advantage of new machine capabilities and improvements. We would have learned much about computers in so doing. But in a project for a medical information system, we must anticipate what we plan to do in such circumstances. We had elected *a priori* not to change until the entire system was proved and specifications for a total system were relatively complete. We believe that to be the best approach for developmental projects. Another group, in a similar electrocardiographic research effort, started before we did; but changes of computers appreciably delayed its reaching its goals.

We chose a small processor. Although we did not consider it ideal we found that such a computer would work in all of our "market" areas if the mode of

operation was changed. It is our belief after the effort that a task can be done well with almost any set of reasonable tools if one learns how to use those tools.

For a hospital, a health department, a group clinic, or service oriented groups, the usual reason for choosing a specific processor is its cost. Generally, the cost is dictated by what the sponsor has available to give. Rarely will the sponsor give appreciably more or less, though he usually requests detailed evaluation of equipment supposedly for that purpose.

SYSTEM CONCEPT

The model project being discussed yielded output;

1) at definable levels of quality, reliability and speed

2) at a cost resonable enough for current health research, services, and marketability.

Note that we did not say *highest* levels of quality, reliability, or speed. We also did not seek *lowest* possible unit costs. Our analysis of what was needed suggested that our mission, and most medical missions, do not require them. In other words, we accepted the engineering concept of *optimization*. Thus we expected a definable percentage of error in our final product and a cost somewhat higher than comparable for other consumer items.

From our experiences, accepting that other solutions are available, we concluded that a small single processor was sufficient to allow us (a medical-engineering research group) to fulfill our medical mission objectives. "In house", the system was used at various times, for example, in teaching;[7] to monitor the performance of data acquistion systems for engineering reliability and ease of operation;[8] and for the logistics of scheduling, recording, and transporting data.[9] The system was used to analyze, for further research or statistical purposes, electrocardiograms recorded alone or sequentially with other medical signals, and for spirograms, blood pressure, tonometry, and other procedures. Our experience indicates that other research and development groups can also expect satisfaction from the use of small single processors.

We also concluded that we had a suitable electrocardiographic information system for hospitals, health departments, and group practices (the other three markets mentioned).[10,11] We would make no claims for having found the ideal solution for all market needs, but our conclusions appear justified by demands for use and purchases of similar equipment and current commercial marketing interest.

The second most important point gleaned from our experiences is that a small processor for use in service areas must be designed to fulfill a total system concept. Medical information that is to be analyzed must be collected by means of a data acquisition system that is capable of communicating with a computer system. The acquisition system should be compatible with communication network for immediate communication with the computer user. Display must be user oriented.

The system components now commercially available as a result of stimulus by this project, which are compatible to form a system are AT&T's analog dataphone series,[12] Computer Instruments Corporation's analog and telephonic data acquisition sets, Beckman Instrument Corporation's digital data acquisition sets,[13] and a (Control Data Corporation's 1700) dedicated electrocardiographic processor.[14] Available with the latter (at no cost since it is, we believe, government property) is a Fortran software package based on software developed for our small single purpose processor.

Several electrocardiographic service groups or companies are currently being formed with these or equivalent components. Industrial entry and marketing, we believe, are needed to provide the basis for the giant steps required to increase the capacity of our health care delivery system.[15] We believe we have learned that health service delivery cannot be improved unless industrial technology (which includes business) is fully brought into its appropriate position in medical system development and health service delivery. This is not to say that unforeseen problems will not also enter the health field when industry makes a major inroad.

SYSTEM UTILIZATION

The basic model system was originally conceived only as a demonstration that large numbers of one type of medical signal in the quantities required by various hospitals, could be analyzed by a digital computer. The commercially available systems carry that demonstration forward into the objectives of health service delivery agencies.

Data from various user groups have been utilized to test and validate the system under the workload conditions of the four classes of user we have mentioned, and have included various types of routine signal processing.

Seventy percent of the nearly 50,000 medical signals analyzed annually are electrocardiograms; 10 percent are spirograms. A small percentage comprises

consecutively recorded but intermixed electrocardiograms and spirograms. Currently 90 percent of the data are recorded on analog acquisition systems and 10 percent on digital systems. Ninety- five percent of the data are received via mail, 40 percent via analog data transmission lines, and 10 percent via messenger. Ninety percent of all data are transported to the laboratory after tapes are filled; the remainder, in batch quantities of up to 1000 electrocardiograms. Results are returned as needed by users. Employee health screening program analyses are returned within ten days. Research project data turn-about times of even one month are acceptable. Hospital work is returned within 24 hours.

LARGE COMPUTERS

If one has enough problems of great magnitude, as in a large statistical study, the largest and fastest computer might be the best. Consider networks such as those of the U.S. Geological Survey.[16] Here, a large computer is used to solve computational problems as they arise nationwide. One wonders why we in the health field have not yet considered this type of effort to be useful to medical research scientists faced with single application-large data base problems. A staff of 90 working 6 days a week is all that is required by the Geological Survey. Located centrally, such a system could add to research quality, decrease grant and contract expenditures, and at the same time build up the staff's knowledge of aspects of medical computers at the user interface, rather than of the development of computers per se.

In reviewing large computers, we note that computer core costs have decreased appreciably but computation costs of large-scale computers with multiple peripherals have increased over the past few years. This has been recently noted by both physical and medical scientists.[17] An appreciable portion of the cost of the large computer doing several jobs lies in programming for the internal operations required. One relatively large medical system, that developed at Salt Lake City by Warner, is being subjected to usage and cost tests in various locations in this country.

In certain significant projects, we have learned much about large medical multiprocessing systems, including their problems. An initial venture, never fully completed, was that of the Veterans Administration and the Systems Development Corporation at the Los Angeles County Hospital. A recent effort by General Electric (Medinet) has been significantly diminished in scope.

Multiprocessing systems are under extensive development in areas other than medicine. Since current commercial computer technology available to medicine far outstrips our needs, it does not appear that medical research and development or scarce medical manpower should now go into basic computer development at the expense of our vital medical and health service missions. Our prime need is to develop available technologic products into systems that will serve health care needs.

SMALL COMPUTERS

As everyone with a computer soon discovers, the amount of scientific or medical input available to almost any computer from any one source is limited and far under most computers' output capability. With our model project's CDC 160A, we had achieved what in the early '60's was predicted possible only with a large 7090. This appears to be developing an argument for relatively small computers in medicine. Hierarchies of single purpose machines within a network appear to be capable of meeting our current needs. The medical sales of DEC (900 computers) as contrasted to sales of larger computers seem to support this statement. Commercial groups appear to be heading toward development of small-system versions of large ones, such as the Salt Lake City effort.

INFORMATION SYSTEM SIMULATION

We have referred to a hierarchy of computers.[18] In our model project, we experimented with what was essentially a multiple computer information system. Components of this functioned at various times. A PDP-8 was used to simultaneously accept electrocardiographic, spirographic, and blood pressure data in analog form.[19,20] The computer determined the type of datum being input and analyzed form.[19,20] The computer determined the type of datum being input and anlyzed it accordingly. The analyzed datum could be transferred on-line to another small computer for interpretation and display (CDC 160A or 8090). The CDC 160A performed the analysis, the 8090 displayed the signal interpretation on a CRT, a teleprinter, and/or a high speed printer. The output could be returned to the user via dataphone (for immediate

use) or voice (Mitre Corporation's IBM 1800).[21] The data from the 160A were also transferred by a terminal to a Univac 1108 for statistical trend analysis and storage.

The system is a small scale model for a general medical signal information system that could perform real time analysis of several signals simultaneously, and return statistical as well as conventional interpretation by various displays. Current telephone communications (as interfaces) and today's display methods with specialized data acquisition devices could make a total information system practical. It would be useful to integrate such a network with existing medical business systems.

The advantages of modularity are clear. The "terminal" operation is independent. The integrity of the system is not dependent on any of the single elements. The user can design input/output format and retain control of privileged information. Since most of the processing or analysis is done on site, the data reduction achieved can reduce data transmission costs. The reduced data from multiple terminals can be used to conserve cost by full computer utilization. Since a system implies more than a computer, one may find that, in the total system, some of the functions one might have required of the computer alone might already be performed in another part of the system.

This brings us to our third point of importance: interfacing research may well be the real current need in the area of medical computers. The word "versus", in the title of this paper, implies a concept that need not play too great a role in our thinking about medical computers.

The message of this presentation is that the key to obtaining the best from any single piece of equipment is not the choice of a specific processor, but the ability to visualize and design the total medical system package.

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A STATEWIDE MEDICAL INFORMATION SYSTEM

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INTRODUCTION

There is no state-wide medical information system, in Missouri or elsewhere. Such systems have been widely discussed for at least ten years. The concepts concerning such a venture have changed a good bit over this time. Consequently it may be worthwhile to consider some of the recent alternatives, some of the problems, and in the context of the problems to examine the fact that we do not see actual state-wide systems at present.

A medical information system would be made up of individual successful subsystems - for example, general hospital record systems, outpatient records, office care records, etc. Participants - especially professional participants - have always been uneasy about centralized "master minded" type planning. They prefer and deserve to be able to adapt information systems operation to local strength and contingencies. Regrettably, very few efforts to construct even the subsystems have been successful. Speculation concerning these many failures and few successes has been presented elsewhere.[1] Suffice it to say that a few successful subsystems have been created - not very many in any one institution; that an even smaller number have been successfully transplanted to subsequent institutions, and that generally, these have been subsystems associated with hospital practice. The few successful subsystems and the well-recognized need for improved information handling in medicine argue strongly for continued support for experimental hospital computer systems. Indeed, successful subsystems should be more widely studied and their impact on health care firmly documented. These existing subsystems concern, however, largely single

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institutions or single functions throughout a region. The concept of a true state-wide medical information system would be quite another thing entirely, involving coordinated data collection and use by many types of health care providers and users.

PARTICIPANTS IN A STATE-WIDE MEDICAL INFORMATION SYSTEM

Listings of health care practitioners, facilities, capacities for care, utilization, and actual records of patients cared for would have to be collected from general hospitals, outpatient clinics, periodic health examinations, physicians' offices, and records of care from specialized facilities such as Veterans Administration hospitals, mental disease complexes, infectious disease sanatoria, cancer hospitals, convalescent and nursing homes, visiting nurse services, and at least partial transaction records from drug retailers. No less complete a set of participants could provide a true picture of the cost of illness (versus the cost of hospitalization), or a true picture of the routes by which patients obtain health care.

Formation of such a network will require the enthusiastic participation of the various state, private, and semi-private institutions; substantial development and operating costs; solution of some rather serious technical problems, and successful resolution of some social questions. The social questions associated with a state-wide medical information system, that is the interface with the public, have been largely ignored in the past by medical planners. This is unfortunate because fundamental problems remain unaddressed, and there is now virtually no "constituency" for such a system outside of computer aficionados.

THE SOCIAL QUESTIONS

Purpose. Why do we want a state-wide medical information system? Just what benefits does this offer the individual citizen? Are we sure we know? If so, why can't we say it more plainly and with more conviction?

Surely the great cost of such a system is not proposed merely so that records of former treatments can be electronically forwarded to the next stop in the patient's care itinerary. If this were our major objective, surely we would provide each patient with a copy of his medical record! That we do not do this

may well have more to do with the medical profession's desire to preserve its mystique than with the hypothetical psychic trauma to the patient in having access to the truth. It is hard to imagine that patient records (whether problem-oriented or system-oriented) would not improve fast and notably, were they available to the persons actually served.

Does the proposed state-wide system merely have as its prime purpose, to make available to each patient through the physician he chooses (who will unquestionably be his townsman) access to those advanced and beneficial services that are too expensive for the individual physician or local hospital to maintain? That certainly sounds desirable and sensible. What are these services? Irradiation, surgery, laboratory, blood transfusion, and obstetrical delivery all require transportation facilities, not telecommunication. We must be thinking about special information processing services. Are these the automated interrogative patient history; interpretation of the electrocardiogram and electroencephalogram, pulmonary function calculations, computer aids to the physician in differential diagnosis or a review of the literature? If this is the case, whose analytic systems are we prepared to endorse, and how do we get endorsement or utilization by the participants?

Is it the real purpose of a state-wide medical information system to provide a data base for research by health care practitioners, administrators, and planners? As a voter I could understand this, although I would probably like a little more information concerning whose interests are being looked after by whom, especially since my own personal records and those of my favorite local charities will be among those examined. Who is the advocate of the *patient* in our present health care system, anyway? Most patients in a university or public hospital cannot even correctly name their own physician, let alone the director of the computer center. It is possible of course that the planners really intend that the data base (including me) be used by research doctors who are trying to discover new ways to diagnose and treat illnesses. This also seems like a reasonable and saleable objective. It does seem a little strange, however, that some such experiment could not have been successfully completed in one hospital first before planning for an entire state.

Perhaps the real purpose of the state-wide medical information system is to get into one system all the information about where a patient could be sent for treatment. One hears of persons dying in the police car or taxi as it seeks for a hospital with an empty bed. In at least one such case in Missouri, the patient was a veteran and many beds were empty in a V.A. hospital. Certainly in large cities there is the additional factor that hospital staffing and referral practices operate in such a way that diagnostic facilities, consultation, and even hospital

privileges have not been extended to many practitioners. Connection with a computer network could certainly aid such a physician in getting assistance - if we really wanted him to get help. On the other hand, it is grossly apparent to anyone old enough to vote that use of the existing telephone services would serve much of the same function - provided there was good will on both ends of the line.

Finally, we must consider that a state-wide medical information system might be aimed at automation of services to patients so as to reduce the rather alarming cost of care. Yet those who have worked on implementation of medical subsystems are the first to warn that computers in medicine do not actually reduce budgets. This can usually and honestly be sugar-coated with the stated expectation that in the future a higher volume of care can be administered by the automated facility. Again, this justification for a state-wide system is less than exciting.

In short, there doubtless are a variety of socially useful purposes to which the information in such a system might be put to improve delivery of health care. Plans for such uses (as opposed to details of electronic processing) have not been well articulated. There is at present no public demand for such a system. Indeed there are some serious public misgivings and prejudices yet to be acknowledged and overcome.

Privacy. The question of invasion of personal privacy is the dominant problem in construction of very large publicly supported data bases - at least those that retain the association of individual data items with the identification of the person. Obviously, a system must retain such identification in order to be really useful. Much has been written and said about the problem, including extensive testimony to three congressional committees,[2,3,4] several monographs,[5,6] and the establishment of study groups within professional and industrial groups.[7] (The latter include "Study to Determine the Extent of the Invasion of Privacy and Freedom of the American People", Maritime Trades Department of the AFL-CIO; and "Committee on Privacy and Security", the Business Equipment Manufacturers Association.)

At this point it appears that adequate means of legal redress are probably available to an injured person after his rights of privacy have been invaded. Unfortunately, everyone seems to agree that this will not prevent the invasions, and that unauthorized access to computer files could well occur without leaving a record of the transaction.

Writings about this danger make reference to wire-tapping, infiltration by criminals into commercial information organizations, illegal exchange of

information between government agencies, inappropriate use of information for purposes wholly different from those for which its collection was authorized, and anticipation of heavy-handed and cruel use of information by well-intentioned but unimaginative hypothetical public servants. All of this sounds to the medical reader a bit alarmist, especially when we recall the low level of security ordinarily associated with files of paper records of hospitalizations. This may be so; but it is the public and their elected legislators whose anxieties must be alleviated, not just the medical profession. Furthermore, who would deny the possibility of such misuses of data, of the much greater availability of information within computer systems, or the presence of certain major unanswered questions concerning the privacy of medical data?

These unanswered questions include the following: What portions of the medical record are public and which are private? Swedish law had defined this distinction before the creation of the Stockholm County information system. U.S. law has not. Does the individual citizen have a right to examine his records and to force correction of errors? What means are available to us to establish the personal identity of the patient? To what extent is a patient's consent for release of his records truly voluntary rather than coercive, if this is the only means he has to accomplish payment of his bills by a third party payer? When the payer is the federal or state government, what rights and protections limit the further uses to which these data may be put? With respect to the latter question, we must remember that it is a cardinal principle of good data processing that items of information are to be collected only once, and consequently that relevant information from many sources is always to be combined in the computer record.

Depersonalization. Medical experts dismiss out-of-hand the problem of the depersonalization of care which accompanies automation. The public does not. An exception is the electronics systems associated with coronary intensive care units, where we have not only successfully associated these techniques with the glamor of the space probes, but where the profession has been able honestly and enthusiastically to point to lives saved. Are we now ready to defend the state-wide information system on comparable grounds? Why not? Are not automated interrogated histories better than the old style? Similarly, are there not real advantages to comparable electrocardiographic and clinical laboratory systems?

The American people seem not to be unalterably opposed to automation even when it does mean depersonalization if the new systems are less

expensive than the old and when they really work. I cite: automatically switched telephone systems without "central" operators; unattended passenger elevators; electronic dictating equipment in place of stenographers; computer airline reservation systems; serve-yourself gasoline stations; and the computer dating service.

Cost. A state-wide medical information system will cost $35-$50,000,000 to build and at least $3,000,000 a year to operate. At present no state or federal bureau is in a position to make this kind of commitment. Expenditures at this level are and should be a matter of public policy. Again, the question of an informed constituency.

The problem is by no means insuperable. Smaller grant funds do exist. Substantial resources exist within the various state agencies and private health care and insurance institutions. Coordinated efforts between these parties could well be the best means of developing compatible subsystems. This approach would also facilitate allocation of information sytems costs to whatever health care transactions are themselves benefitted by the system, rather than to a specially segregated information system project.

TECHNICAL PROBLEMS

It is difficult to define with certainty the technical problems when the very nature of a proposed state-wide medical information system is yet so indistinct. Even so, four major technical problems may be noted. These would likely be pertinent to many kinds of geographically divided information networks.

Patient Identification. There simply is not a good system for identifying an individual in a medical setting. This is a fundamental technical problem. The various logical numbering schemes, the concept of uniquely numbered patient record, wrist bands, collection of family information for redundancy, all alleviate the problem but do not solve it. Fingerprint analysis for this purpose has not become realistic. Specimen identification is a subset of the patient identificaton problem. Here too, preprinted labels, machine-readable stub cards, bar-coded orders, etc. alleviate the problem. A major step forward in addressing the patient and specimen identification problem for the individual hospital is the incorporation of calculated check digits within the numbers that identify the patient and/or the specimen. Half of the errors detected by the computer laboratory system in our institution were caught by checking digits.[8] Other segments of the institution and most other hospitals, however, do not employ even this feeble protection against erroneous identification.

Sweden and England use a logical and, it is hoped, unique identifying number for each of their residents. Acheson has commented at length about the record-matching problem even under these ideal circumstances.[9] The validity of a medical record must be viewed not as a fact, but as a statistical likelihood, where the chance of validity varies greatly with the source and nature of the medical item.

Terminology. Terminology in medicine is far from uniform. This is a serious problem in even a single hospital. Were this not so, we would not be obliged to use check sheets and numerical codes. The problem on a state-wide basis is enormous. At present no terminology has any real authority across institutions and even less across specialties. For example, what is a "radical breast resection", a "negative Coombs", a "normal chest film"? How were these performed? The problem would be no worse in the computer system than in a manual record were we to include all the redundancy of the records which make it possible to avoid misunderstanding. This would not be acceptable to most systems planners; hence the fundamental nature of the problem.

The former comments related largely to precision of expression. There are also legitimate differences of opinion concerning semantic content of medical expressions (e.g., cysts, cancer, fever, weakness, metastatic, osteoblastic, hypertension). These matters could be addressed by properly constructed thesauruses.

The optimal size of a medical vocabulary is not yet known. The AMA's *Current Medical Terminology* contains 14,000 words;[10] Lamson's *Thesaurus for Surgical Pathology* contains 9,000 words;[11] the Kaiser-Permanente word list contains 70,000 items. So far the only reasonable criterion for adding or deleting words appears to be utilization.

Very Big Files. Medical files as large and as complex as those involved in a state-wide system have not yet been assembled or processed. From what is available in the public literature, it appears that military and criminological files of this sort, while sometimes very large, are not at all as complex as the medical ones. The complexity seems to stem from not knowing for certain the exact makeup of the data items, the necessity to include variable length and even free-form items, the bewildering speed with which terminology, determinations measurements, and even organization of medical records change, and the necessity for user-defined record layouts. In addition, the number of erroneous items anticipated in medical files is large.

Certain principles have become clear from the initial attempts at building files of this sort. (1) Records stored must be hierarchial, with infrequently used records kept on low-cost devices and frequently used records kept on high-speed and hence more expensive devices. This implies activate/deactivate and reorganization routines. (2) The file building, maintaining, and accessing routines associated with a medical computer application consume more programming and systems time and dollars than the applications code. In one system in Missouri 22 percent of costs went into the application; 78 percent into file systems and accessing routines.[8] This implies that file creation and maintenance - at least for an institution - must be provided once for all systems. The challenge is to do so without compromising the alternatives and flexibility of the applications systems. (3) Based partially on the arguments cited, it appears clear that there is no finite series of tasks in medicine which ought to be programmed for a computer; rather, these systems represent a permanent way of life and require a permanent technical interface staff. (4) Health care personnel using large files for other than superficial inquiry or single record retrieval seem to do best by working with a technical assistant. The present weakness of "user languages" is not so much in the command structure as in the inability to simplify the inherently complex structure of the file, the history of the data collection, and the necessary inconsistencies between the items which originate in different parts of the information network. For example, in our own system it is easy for the user to retrieve records of patients with abnormal blood urea nitrogen determinations, even to compare on-line the results with two or more different populations in several sites within the state. But *caveat emptor*. How can we explain simply, that some measurements were performed manually, some by linked continuous-flow analyzers, some by peak-picking analyzers; that three laboratories may have been involved for the work in one institution, and that the methods will undoubtedly have changed over the years? The data reflecting all these factors are present, but the users cannot utilize them simply. Incidentally, our recent experiences indicate that data characterizing the population to be compared - especially the selection of populations or patients - bear more significantly upon the evaluation of results than do the technicalities of the measurements! For example, suppose we examine a group of glucose tolerance tests, for whatever purpose. They are meaningless unless we know the reason the patients were referred for care, and the reason the examinations were ordered.

Reliability and Failures. The bare truth here is that computers do fail, and also require scheduled down-time for preventive maintenance and for installation of engineering changes. Down-time on our previous batch processing

IBM 1410 was 5-6 percent; operation was essentially satisfactory to the users. Down-time on our IBM 360/50 with many on-line systems has been 2-3 percent; operation is unsatisfactory to users. Back-up machines are essential but, at the same time, too expensive. The usual compromise is to provide a reasonably nearby back-up system to be used in case of prolonged "hard" failures. A better scheme would be a service computer, software and hardware coupled to a research machine that could be used in emergencies for service.

Data Transmission Costs. Costs for transmission of data via telephone lines over a network about equal the costs for computer rental, and probably exceed the computer problems in complexity and importance. Clearly, the whole issue of back-up systems, ready access to distant medical communities, interactive inquiry for users, integrity of systems against unauthorized invasion of privacy all hinge primarily upon the capacity, adequacy, and cost of the data transmission services.

Time-share systems purveyors have grandly proclaimed their ability to serve many hundred users simultaneously - provided the users have antique 110 baud keyboard terminals. This is capitalizing upon weakness. The recent popularization of graphic display terminals and CRT character display devices tends to emphasize that far greater transmission capability is actually needed by users - even though their typing speed *per se* remains very slow in relation to the internal computer speeds.

A more important issue is, why cannot remote computers be connected through and share a file device, thereby providing back-up to the medical applications as well as coordinated processing of information? Simple: because information leaves the disc files typically at 350,000 bits per second and even Telpak C provides only 48,000 bits per second transmission capacity. More recent telephone systems (D1 and 2 channel bank and T1, T2, and T5 transmission lines)[12] use pulse code modulation for digital transmission of multiple conversations. These can provide more than 500,000 bit per second transmission over a simple voice pair. Further than this, community cable-T.V. systems provide two orders of magnitude greater capacity but have not yet been incorporated in medical information systems.[13] Planners for a state-wide medical information system must recognize the prime importance of the transmission systems problems and come to understand and use the very best facilities.

EQUIPMENT CONFIGURATION FOR NETWORK

Thinking in this field has usually used a conceptual model of a hypothetical large computing machine which performs many functions for the benefit of the numerous stations connected to it. Sometimes peripheral computers have been placed in the network to concentrate messages, preprocess incoming data, or switch messages (Fig. 1).

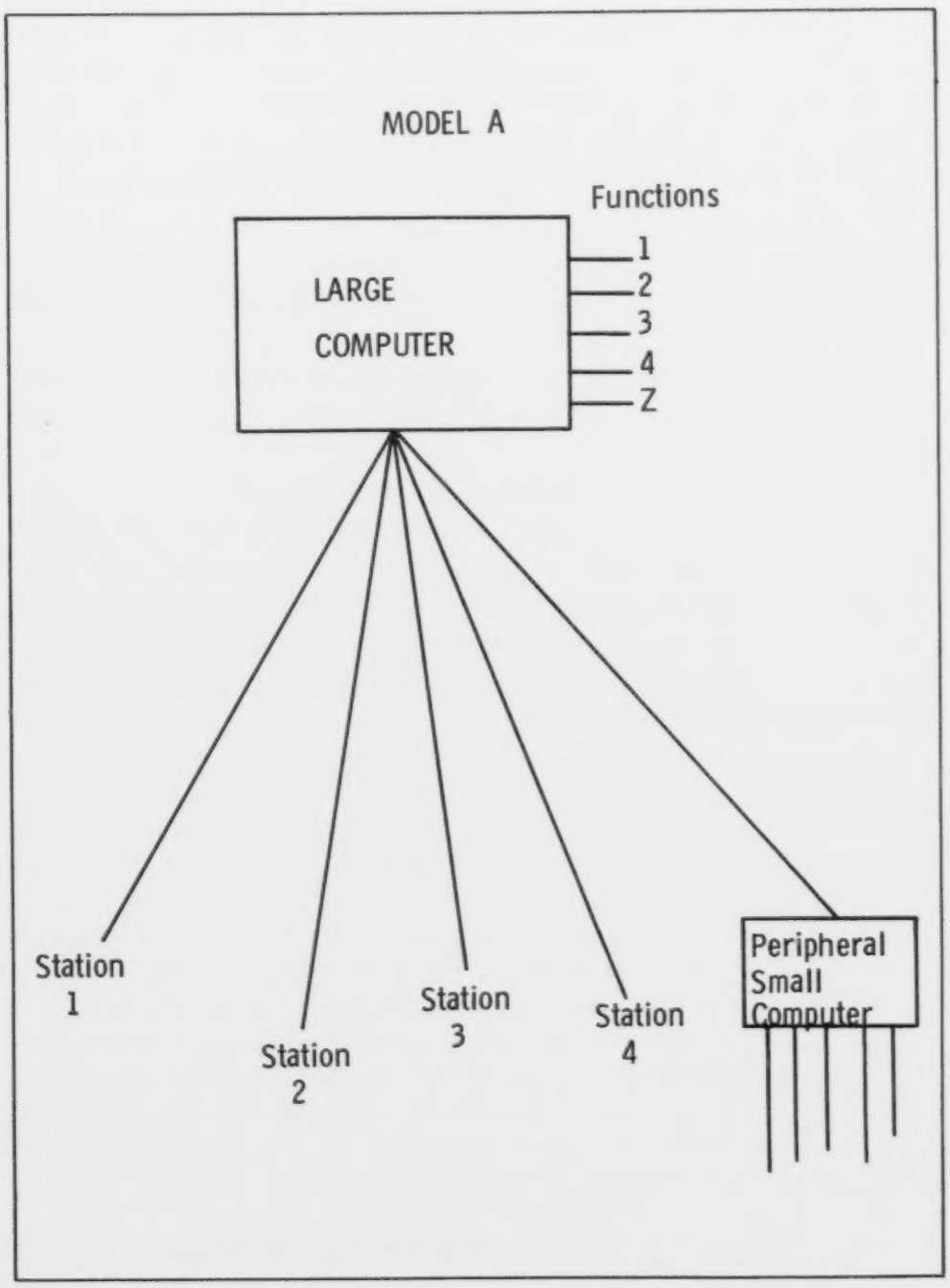

Figure 1. Traditional conceptual model for regional medical information system.

An alternative conceptual model should perhaps be considered (Fig. 2). Multiple medium-sized computers could be dedicated, each to a single function

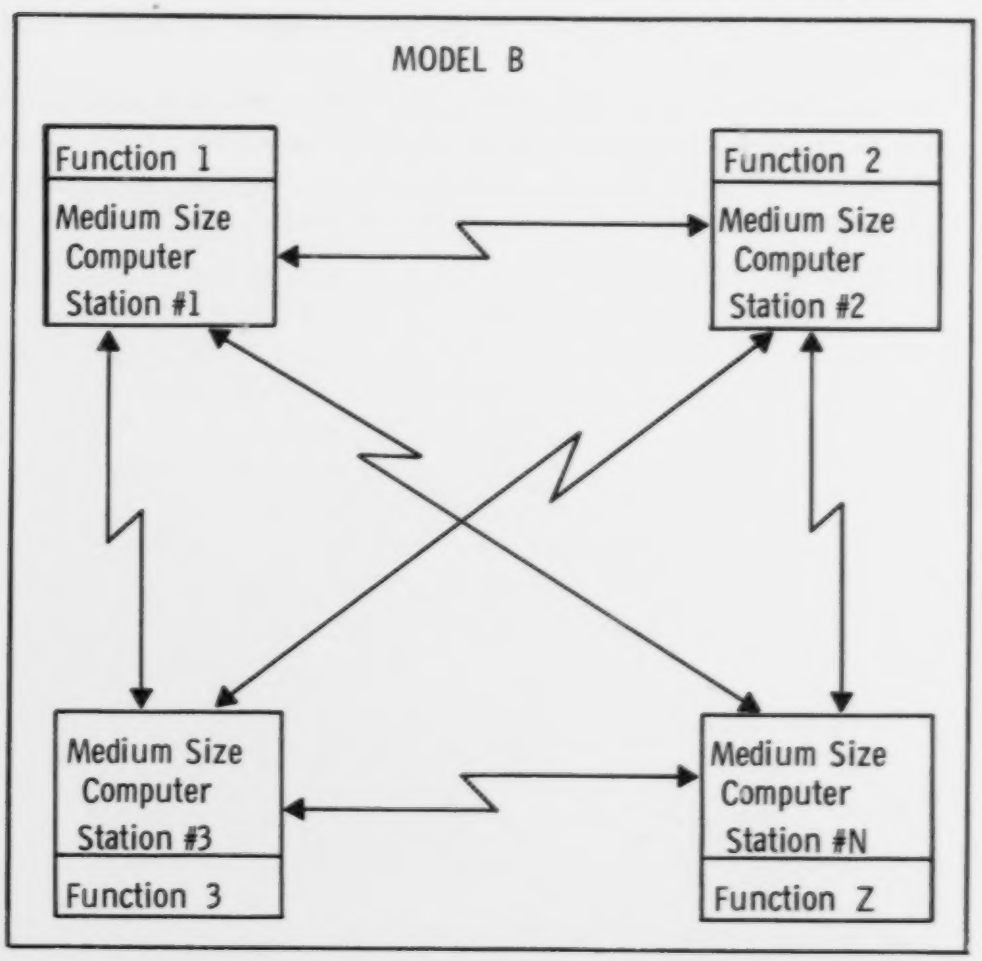

Figure 2. Alternative conceptual model for regional medical information system.

or subsystem; and each, via a suitable transmission system, could serve all the stations. In either case, typical functions would be: admission/ discharge/ census; automated patient history; interpretation of physiological signals; bloodbank management; general laboratory data transmission; diagnosis assistance; mathematical analysis; menu planning; nurses' notes; patient scheduling, and special laboratory procedures.

Advantages of this model are:

1. Each installation is justified by providing a known service to the region.

2. The services are easily identified and explained; those of benefit to patient care can be allocated to patient care costs.

3. Responsibility and authority for creation and operation of the system are decentralized, giving the numerous agencies a chance to be creative where they desire to be.

4. The creation of state-wide central files remains entirely possible but is subject to negotiation and surveillance by all responsible parties.

5. Most important of all, such a model permits the continuity of the design groups responsible for creation, maintenance, and improvement of each of the subsystems.

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THE KAISER-PERMANENTE

MEDICAL INFORMATION SYSTEM

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INTRODUCTION

Information processing has been reported[1] to account for approximately 30 percent of hospital per diem costs. This has been confirmed by recent studies of two Kaiser Foundation Hospitals.[2] In the past few years there have been striking advances in electronic data processing technology. During this time attempts have been and are being made to adapt various data processing methods to selected aspects of medical care.[3-6] The rationale for this approach has been that computer methods can be expected to improve the accuracy and utility of medical records and, if not reduce the absolute costs of data storage and transfer, at least make manageable a larger volume of data for the same costs. Such expectations seem indeed rational, but have yet to be realized. Electronic data processing management of truly large volumes of medical information has yet to be demonstrated at a level of operational sophistication that will satisfy the needs of physicians and nurses dedicated to traditional concepts of good quality medical care. In addition, the extraordinary costs of adapting computer systems to the dynamic medical environment give rise to the question: will the costs of the new methods ultimately be less than, equal to, or greater than traditional methods? Computer applications to the medical care aspects of hospital and clinic operations therefore must still be classed as applied research and development. Accordingly, the Kaiser-Permanente Medical Information System (MIS) may be defined as a long-range research and

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development program being conducted by the Department of Medical Methods Research.

LONG-TERM OBJECTIVE

The objective is to develop a multifacility computer-based system that will support the medical data requirements of one million health plan members, one thousand physicians, and a large corps of professional and paramedical contributors to patient care.

At this time, such requirements cannot be specified with precision because of the current lack of understanding as to what constitutes, in given clinical situations, essential medical data, lack of standardization of the medical care process, and the unpredictable but dynamic effects of medical and technological research and development.

However, certain functional requirements are recognized. A partial list is presented in Table 1, and some perspective may be gained by observing a few of the characteristics of the operating environment (Fig. 1).

The "system" needed to satisfy these requirements similarly cannot be specified with precision. Here also, certain generalizations can be made; the general requirements of an MIS have been outlined by Collen.[7] It follows that a modular approach to the development of a large scale medical information system is mandatory, and that careful planning, testing, and evaluation are required at different stages of development.

THE CENTRAL COMPUTER FACILITY

The long-term objective outlined above can be approached by one of two basic strategies: (a) treat each hospital and clinic facility as an independent data processing entity; (b) treat each hospital and clinic facility as a "terminal station", serviced by a single "regional" data processing center. The latter strategy has been adopted for the first phase of development of the "regional" system defined by the Northern California Kaiser-Permanente Health Care Program.

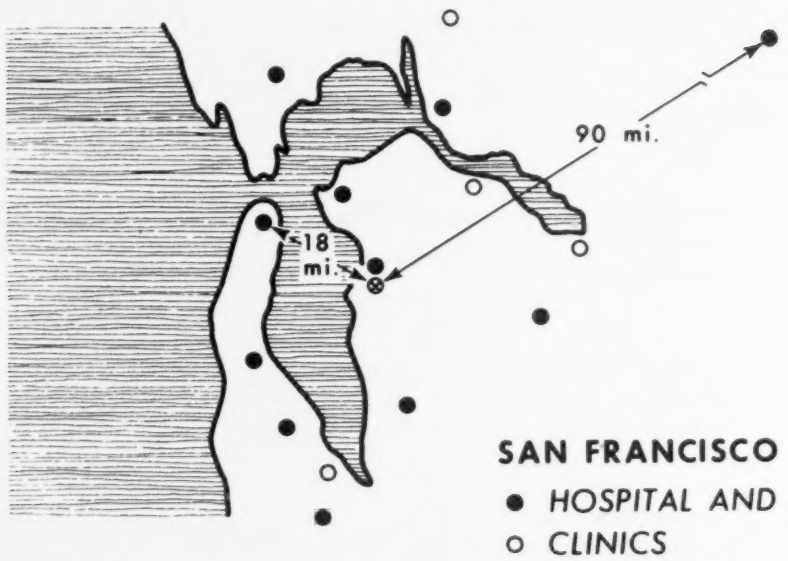
A computer-stored, integrated medical record is central to the functioning of a large-scale multifacility medical data system. Such a record, and the system that maintains it, must be so structured as to store all classes of patient-related data: identification, administrative, and medical. It must be continuously

Table 1.–Selected Functional Requirements

CLINIC FUNCTIONS		HOSPITAL FUNCTIONS	
APPOINTMENTS:	New Schedules Reschedules Cancellations	ADMITTING	
PATIENT REGISTRATION:	ID Verification Eligibility checking	NURSING STATIONS:	General nursing Intensive care unit Nursery Post-operative recovery
PHYSICIAN SERVICES:	General purpose reports Special purpose reports Real time inquiry to individual records	PHARMACY SERVICES	
		DIETARY SERVICES	
		SPECIAL FUNCTIONS:	On-line patient monitoring
TREATMENT SERVICES:	Allergy laboratory Injection clinic Minor surgery/ special procedures Optical laboratory Pharmacy		

FUNCTIONS COMMON TO CLINIC AND HOSPITAL

MEDICAL RECORDS MAINTENANCE
CLINICAL LABORATORY/PATHOLOGY
RADIOLOGY
PHYSICAL THERAPY
SOCIAL SERVICES
ECG, EEG, EMG, ETC.
SPECIALIZED FUNCTIONS:
- Administrative & Management Services
- Education
- Medical Research
- Operations Research



SAN FRANCISCO BAY REGION

- ● HOSPITAL AND CLINICS
- o CLINICS
- ⊗ CENTRAL COMPUTER FACILITY

	1965	1969	1975
HEALTH PLAN MEMBERSHIP	645,000	950,000	
PHYSICIANS	590	980	
HOSPITALS: BEDS	8: 1100	11: 1650	
HOSPITAL ADMISSIONS	51,500	80,000	
OPD CLINICS	15	15	?
PHYSICIAN OFFICE VISITS	2,300,000	3,500,000	
LABORATORY PROCEDURES	3,067,000	6,272,000	
X-RAY EXAMINATIONS	432,000	737,000	
PRESCRIPTIONS FILLED	1,200,000	2,000,000	

Figure 1. The operating environment.

updatable, capable of accepting the random quantity and timing, and variable format of data input, responsive to the need for real-time inquiry to individual patient records; capable of supporting broad-based research activities, and sustained by reliable error detection and recovery routines. An operational computer medical record system which meets these requirements has been brought to an advanced stage of development and is described elsewhere.[8,9]

The central computer facility (Fig. 2) consists basically of two IBM 360/50 computers and associated equipment. One computer functions as an on-line device; the second subserves an essential "back-up" function by means of

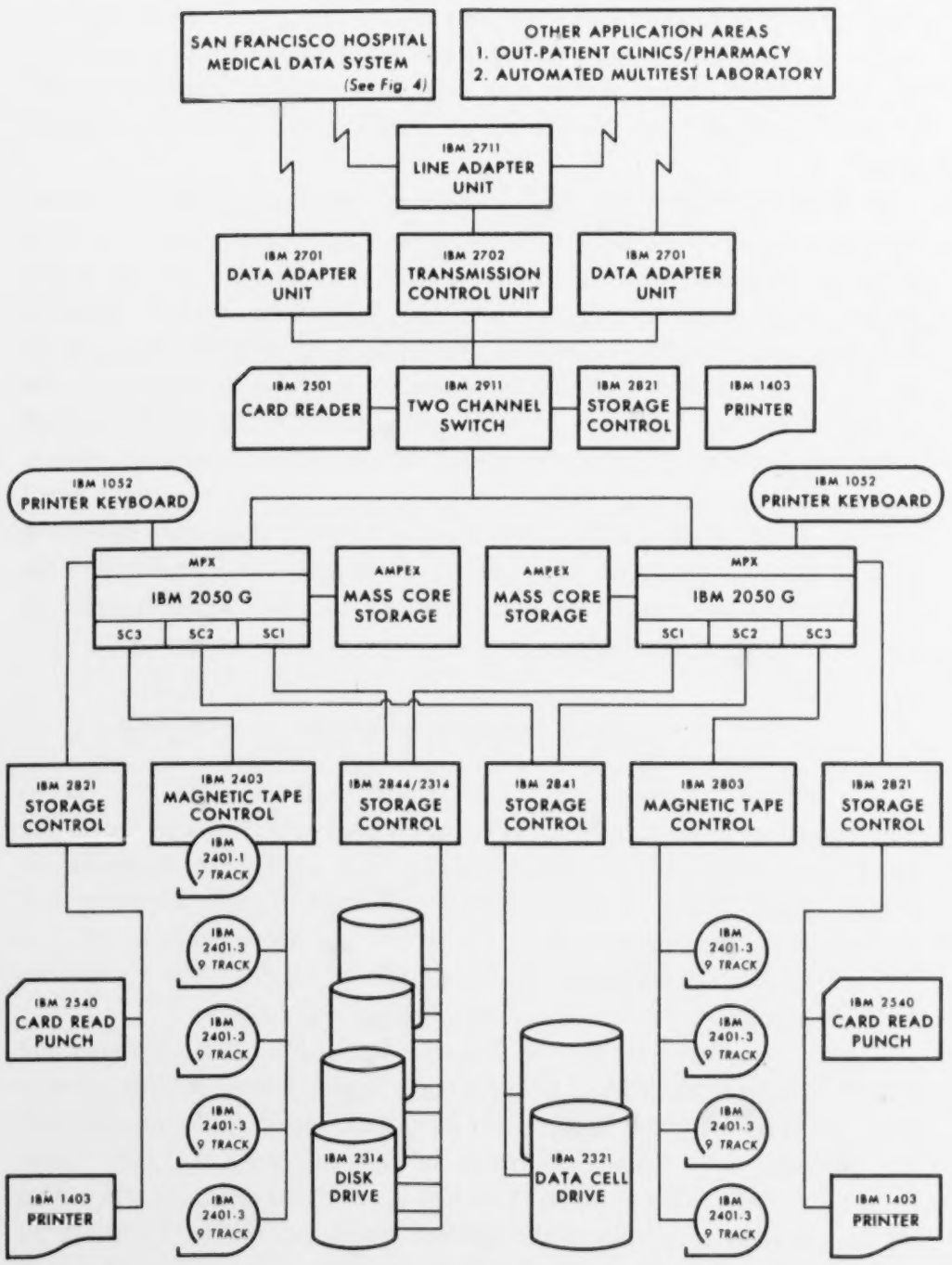

SAN FRANCISCO HOSPITAL MEDICAL DATA SYSTEM (See Fig. 4)
OTHER APPLICATION AREAS
1. OUT-PATIENT CLINICS/PHARMACY
2. AUTOMATED MULTITEST LABORATORY
IBM 2711 LINE ADAPTER UNIT
IBM 2701 DATA ADAPTER UNIT
IBM 2702 TRANSMISSION CONTROL UNIT
IBM 2701 DATA ADAPTER UNIT
IBM 2501 CARD READER
IBM 2911 TWO CHANNEL SWITCH
IBM 2821 STORAGE CONTROL
IBM 1403 PRINTER
IBM 1052 PRINTER KEYBOARD
IBM 1052 PRINTER KEYBOARD
MPX
IBM 2050 G
SC3 SC2 SC1
AMPEX MASS CORE STORAGE
AMPEX MASS CORE STORAGE
MPX
IBM 2050 G
SC1 SC2 SC3
IBM 2821 STORAGE CONTROL
IBM 2403 MAGNETIC TAPE CONTROL
IBM 2844/2314 STORAGE CONTROL
IBM 2841 STORAGE CONTROL
IBM 2803 MAGNETIC TAPE CONTROL
IBM 2821 STORAGE CONTROL
IBM 2401-1 7 TRACK
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2540 CARD READ PUNCH
IBM 1403 PRINTER
IBM 2314 DISK DRIVE
IBM 2321 DATA CELL DRIVE
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2401-3 9 TRACK
IBM 2540 CARD READ PUNCH
IBM 1403 PRINTER

Figure 2. Equipment configuration for central computer system.

manual switching (approximately ten minutes switching time) and is used for off-line research, testing and "de-bugging." Each computer has access to its own set of input-output devices and files; either can be connected to the telecommunications control units, which interface with all remote terminal devices.

In order to support the large number of input-output and processing functions, the Medical Function Control System (MFCS) was developed. This system of programs comprises numerous general and special routines which operate under control of the IBM 360 "Operating System, allowing Multiprogramming with a Variable number of Tasks" (OS/MVT). The essential function of MFCS is to maintain the numerous data sets that constitute the medical record files. Five groups of programs comprise the MFCS: medical record manipulation routines; encoding and translation routines; medical language routines; medical function routines, and a medical function control program. These routines include direct-access storage and handling of remote terminal as well as the usual input and output devices. The central facility has been described in more detail elsewhere,[8-10] as have related aspects of direct-access mass storage systems.[11]

SHORT TERM OBJECTIVES

The immediate objectives of the Kaiser-Permanente MIS are: (a) to establish, in one medical facility, a pilot data system subserving a representative spectrum of functions, and (b) to develop and implement an evaluation program, some of the results of which will be used to guide the design and implementation of data systems in the second and future medical facilities. Selected aspects of evaluation of the effects of medical data systems on hospital operations have been presented by Flagle[12] and Richart.[2]

The site of operation is the San Francisco Kaiser Foundation Hospital and associated Permanente Medical Group clinics. Together, these facilities provide acute and continuing care in essentially all medical and surgical specialties, and are available to a local population of approximately 125,000 Kaiser Foundation Health Plan members. There are about 2,000 physician office visits per day. Average occupancy of the 304-bed general hospital is 85 percent; an average of 39 patients are admitted to all services daily.

Selection of those medical data to be collected, and of methods for doing so, was accomplished as a natural outgrowth of several years of experience with various data processing techniques employed in the development and operation of an automated multiphasic screening project.[13] The techniques include

on-line telecommunications operation on a daily basis and the use by physicians of optically readable mark sense forms. Data collected in the multiphasic screening project include clinical laboratory (selected chemistry, hematology, urine) tests, x-ray (chest) examination, electrocardiographic findings, and physician diagnoses. Accordingly, the specific goals of the San Francisco Pilot Data System are: (a) to acquire, and to store in the computer record of each hospital or clinic patient, on a continuous basis: all diagnoses, results of all laboratory tests, x-ray, pathology, and electrocardiographic examinations, and data concerning all drugs dispensed or administered; (b) to provide limited services to the professional and technical staff, such as printed reports of test results and, in the hospital, visually displayed and printed sets of data (doctor's orders, medication schedules, laboratory specimen labels, etc.)

A summary of the modular expansion of data processing functions is presented in Fig. 3. Evaluation of the performance of various elements of a given data system is expected to provide information that will facilitate the system's own improvement, and that will result in improved design and implementation of subsequent systems.

THE PILOT MEDICAL DATA SYSTEM

The pilot data system (Fig. 4) is separated functionally into outpatient and inpatient sections.

Outpatient Section. All elements of this section are currently in operation. In the medical offices, patient registration and diagnosis data are acquired on optically readable forms for each of the approximately two thousand appointment and nonappointment visits each day. The resulting punched cards are batch-processed daily. In the outpatient pharmacy prescription data, including patient and physician identification, drug data, prescription refill and drug usage dates are entered on-line by pharmacists, directly into the appropriate patient's computer medical record, resident in direct-access mode in the central facility. Labels are produced under program control, to be dispensed with the drug container. In the automated multiphasic screening laboratory, a wide variety of medical data is collected and "advice" rules are generated in real time to aid in follow-up patient care.[13]

Inpatient Section. The hospital data subsystem is in the final stages of development. The basic configuration consists of a satellite processor linked, by duplex telephone lines, with the central computer facility. This processor (Honeywell DDP 516 and 416 with 40K core memory) constitutes the nucleus

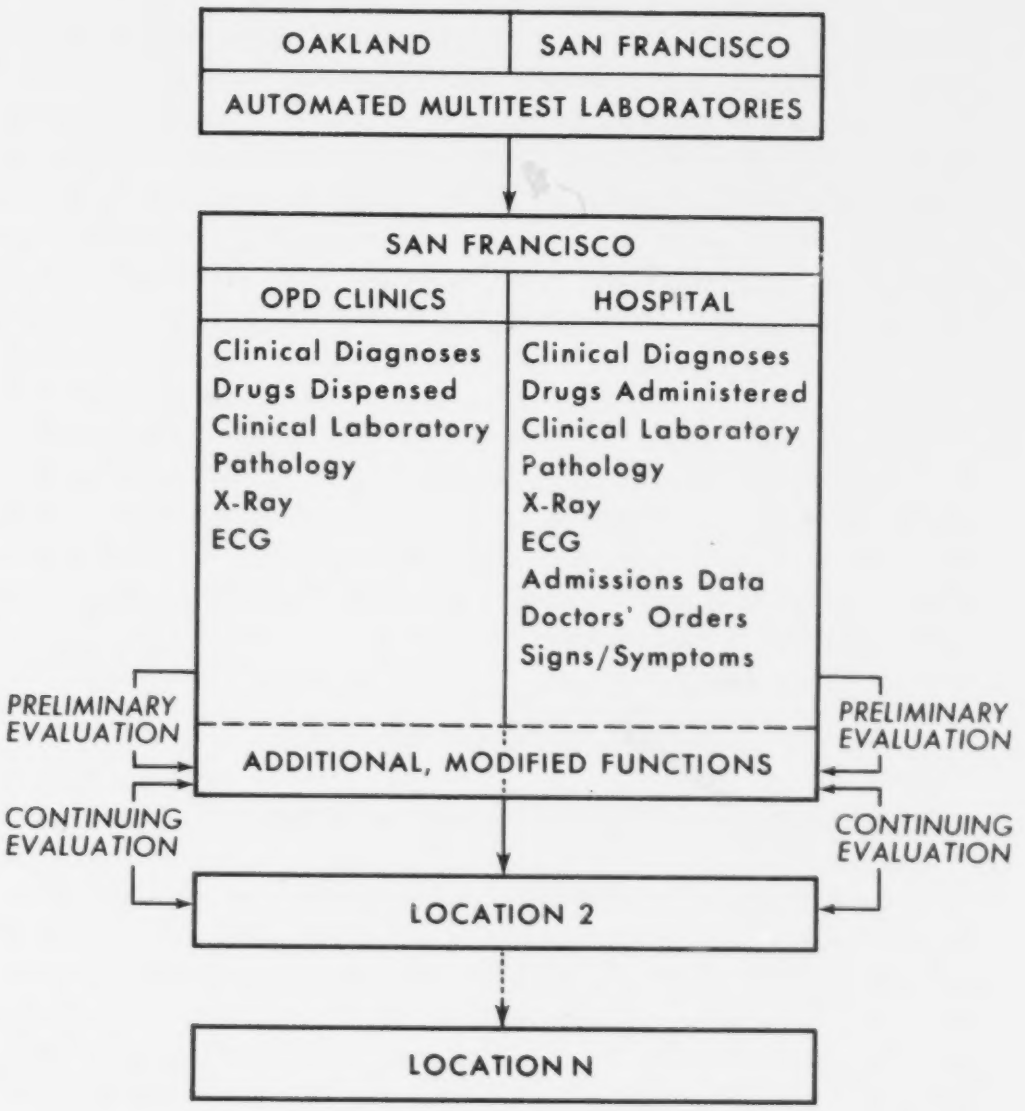


Figure 3 Expansion of data processing functions.

of the hospital system: it has access to six disk drives having a total capacity of 4,704,000 characters. The potential for added core memory (limit of 64K) and added disk storage exists. A noninterruptible reserve power system, consisting of a constant voltage current-limited battery, storage batteries, static inverter, and a diesel generator insures against data loss due to A/C power failure.

The processor drives 24 Sanders Associates terminals, each terminal being defined as a visual display device with associated light-pen sensor, keyboard,

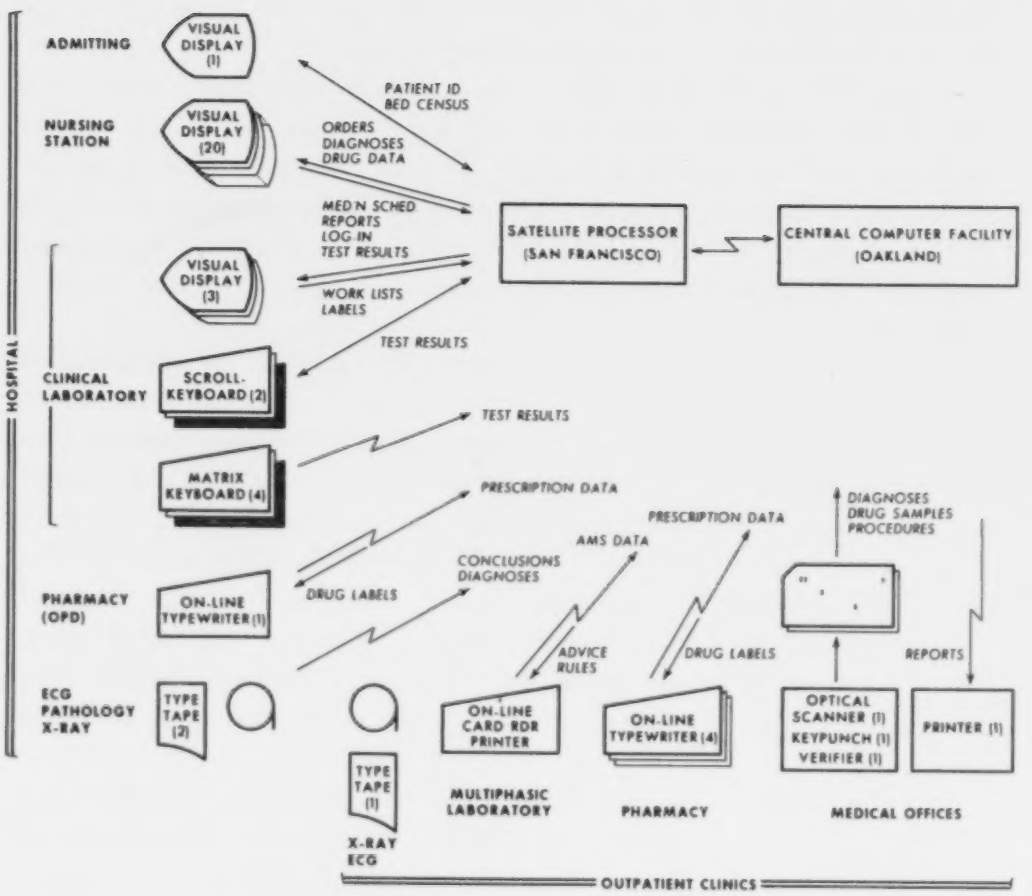


Figure 4. Single facility pilot medical data system.

card-reader unit, and electronic printer. Twenty-one terminals are to be deployed throughout patient care areas of the hospital, including all nursing stations, the nursery, intensive care unit, emergency room and admitting department. The average number of patients per terminal is 16. Three terminals are assigned to the clinical laboratory for logging-in of test specimens, test reporting, and production of work lists and labels.

The system of terminals is that portion of the data system which will interface with medical care personnel including doctors, nurses, and selected technicians and clerks. It will serve for data input and output of patient diagnoses, selected signs and symptoms, physicians' orders including orders for drugs, and general nursing orders, drug administration data, medication schedules, and clinical laboratory, x-ray, surgical pathology, and

electrocardiogram results. A description of the pilot data system, including details of its components, has been published recently.[10]

All satellite system and applications programs have been written in a "JOSS"-type re-entrant interpretive compiler language. Its capabilities are similar to those discussed by Greenes et al[14] and include (a) allowing systems and applications programmers to write, enter, and debug programs directly via the visual display screen, and (b) relative ease of programming by allowing execution of numerous operations while using relatively few program statements.

At the time of admission of a patient to the hospital a file, composed of selected elements of the patient computer record, is called from the central facility and established in the satellite data system in real time. Working with elements of this patient file and various applications programs, the authorized user (identified by his coded machine-readable identification card) may enter or retrieve data by interacting directly with the visual display terminals. The goal of high-quality data acquisition requires that responsibility for data input rest with the individual most capable of assuring its accuracy and completeness. Thus, physicians will enter orders and diagnoses, nurses will "chart" drug administration data, the laboratory technologist will enter test data and so forth.

It is likely that, at least from the points of view of the professional user and the patient, reliability will be the single most important characteristic of medically-oriented data systems. This may be true particularly in the hospital environment, where medical problems are more urgent and the density of data is relatively high. Yet, paradoxically, it is likely that most attempts to implement large-scale medical data systems will begin in this more difficult hospital environment with its demand for a high degree of reliability. Reasons for this are largely economic; they include a dense patient population (fewer input-output devices per patient, doctor, and nurse), and high frequency of data transfer (less idle computer time). These conditions tend to increase the efficiency and presumably the cost effectiveness of a computer system.

A significant degree of reliability of hardware can probably be achieved by redundant or duplex systems. Redundancy permits operation in the "fail-soft" mode illustrated in Figures 5 and 6. As is shown, failure in system "A" of a single terminal is not catastrophic in that a single terminal can be replaced. Failure of any other element, however, including the processor, storage devices, or telecommunications lines results in total system shutdown until the malfunction is identified and corrected. Duplex operation provides the assurance that, if one system becomes inactive, there will always be an

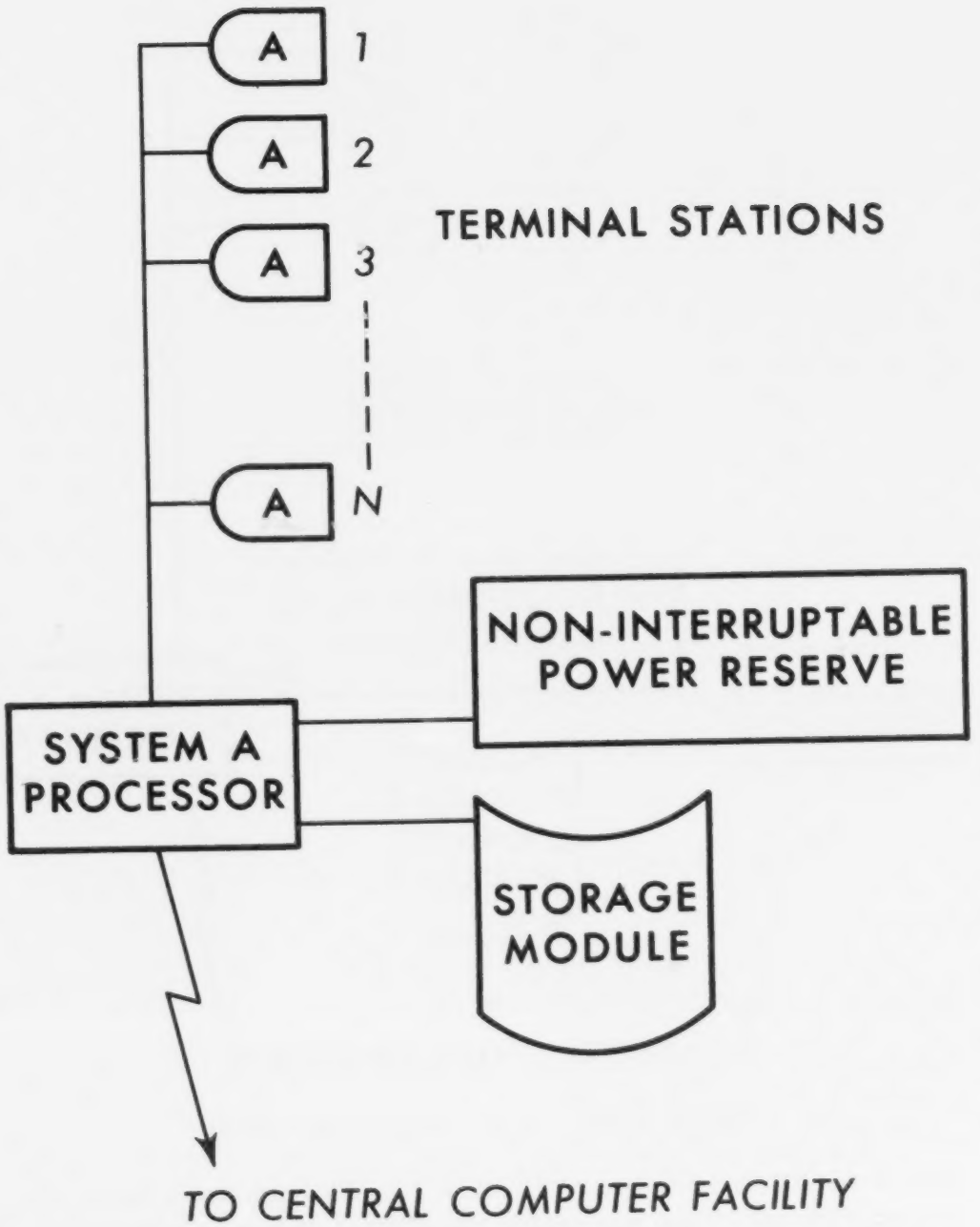


Figure 5. Primary hospital system (A).

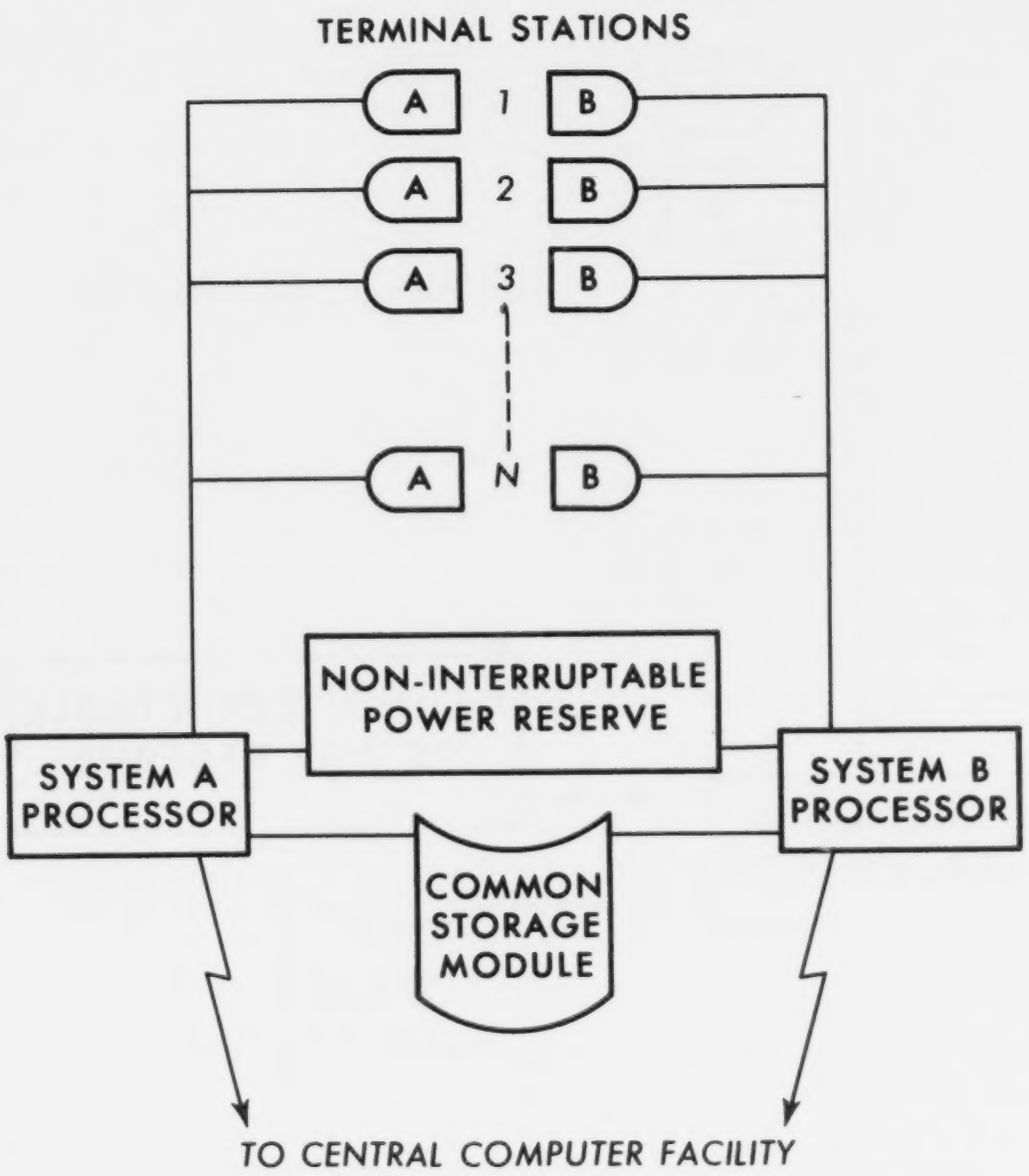


Figure 6. Duplex ("fail-soft") hospital system (A+B).

operational terminal nearby. A duplex system also provides a means for programming and testing new applications without materially compromising service to the professional user. While such redundancy is costly, it is considered essential at this time. A proposal for the single facility duplex configuration is diagrammed in Fig. 7.

Software reliability appears to be a more formidable problem at present. Periodic degradation of system and/or applications software performance can

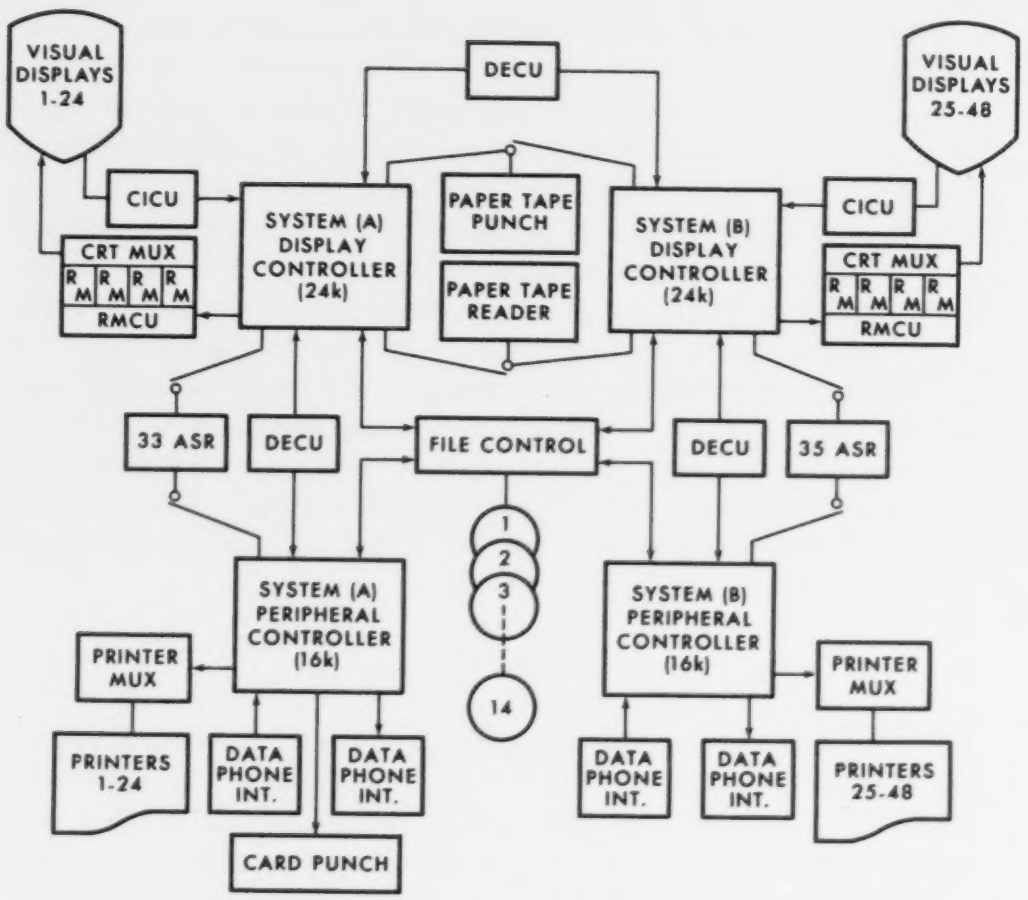


Figure 7. Proposed configuration of integrated computer systems (A+B) for a single hospital.

be expected. There will be need for sophisticated real time error detection schemes. Provisions for rapid error recovery, once faulty performance is recognized, and reasonably stress-free backup support for the human users of the data system will be vital to a successful medical data system.

IMPLEMENTATION

Presently available hardware, while expensive, is probably adequate for most of the medical applications visualized today. The major constraints on rapid implementation of large-scale medical data systems are imposed by software related problems: the quality and scope of input data, the quality of error-recovery methods, and the common gross underestimation of the magnitude of the resources required to deal adequately with these problems.

Central to the implementation of new systems in a working environment is education of the facility personnel, at all levels, with respect to the objectives, scope, and rationale of the methods employed. Clearly, adequate training of user personnel also is essential; training, however, can begin, in selected instances, during system development. Thus, while strategic decisions will have been made previously, many users may profitably participate in end-stage tactical decisions before and during operation of the system. Accordingly, selected physicians, nurses, technologists, and pharmacists have been trained in various aspects of systems development and in applications programming.

Large and/or innovative computer systems do not lend themselves to ready installation and operation; indeed, they often require months of "shakedown." Successful implementation therefore depends on initial operation within a small, functionally clearly defined area of the medical facility. Expansion into new physical and functional areas may then proceed in a more orderly manner.

SUMMARY

The Kaiser-Permanente Medical Information System is a long-term research and development program. Its major objective is the development of a multifacility computer-based system which will support the medical data requirements of a population of one million persons and one thousand physicians. The strategy employed provides for modular development. The central system, where the computer-stored medical records are maintained, and a satellite pilot medical data system in one facility are discussed. Serial expansion to several hospitals and clinics is anticipated.

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HIGH LEVEL PROGRAMMING LANGUAGES

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INTRODUCTION

As illustrated by the papers in this field, there is a great variety of opportunities and approaches to the application of computer technology in patient care. An absolute requirement for these applications is a computer facility to support a coordinated team effort, including computer experts and individuals knowledgeable about the patient care environment and its information processing requirements. For a successful team effort, these hospital-oriented individuals must be intimately involved in the evolution of the system. This can best be achieved by using a programming language and a computer configuration that facilitate rapid development of applications and active experimentation. This need has become apparent wherever computer technology has been introduced, and has stimulated the creation of artificial languages permitting the users to express a problem in terms that are close to a natural language.

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The earliest computers used for medical applications were relatively small, and capable of only limited arithmetic operations; punched cards were their main method of input. Free text in these early systems was treated as a "black glob": the systems merely copied alphabetic data from input to output. In operations characterized largely by the processing of transactions, e.g., billing, payroll, etc., the computers were used to perform the same set of operations on each transaction. These transactions usually occurred as unit records, punched on an 80-column card with numeric codes and fixed length fields.[1] Many patient care applications of computers are still transaction-oriented, using fixed length fields and numeric codes, although there is now more emphasis on applications in which transactions may reference and update a number of different files concurrently.

A major disadvantage of these simple data processing systems is that they cannot evolve into a system capable of meeting the needs for integrated, multi-user, real-time data management. This disadvantage has not gone unnoticed by the new breed of software houses, and a number of systems have been introduced aspiring to be generalized data management systems. It would be foolish to try to review all of these systems, many of which exist only as acronyms. Disenchantment with the unconsummated promises of these systems abounds; they are often grossly inefficient, bound by illogical rules, and require too much time for simple operations. Their most useful contributions have been in two areas:[2] a) ease of developing new applications without long delays or reliance on highly skilled programmers, and b) utilization of the full capabilities of mass random storage equipment for the management of complex data base files.

This discussion is limited to a particular problem area: the design criteria for systems that can support patient care data management activities. A presentation limited to the characteristics of a high level programming language may be interesting, but is inherently sterile. Since one cannot use a theoretical programming language, it is only when these features are realized on a functioning computer system that they have any relevance to an application-oriented group.[3] Thus, the features to be discussed are those of an entire clinical data management system rather than of the language in which they are expressed.

Input Requirements. The different classes of information that comprise the medical record require different types of automated collection. Some of these classes are: (a) simple numerical information such as body weight, temperature, serum sodium level, urine output; (b) positive/negative or crude quantitative information regarding family history of high blood pressure, size

of liver, intensity of murmur, etc.; (c) information that exists in analog form, such as an electrocardiogram. However, the great bulk of information in a medical record is free narrative text.

The single most difficult problem in the application of computers to medicine is data input. If this problem is overcome and the information captured, computer analysis, storage, and retrieval can be relatively straightforward.

A data management system in a patient care setting must have certain characteristics: (a) because no single terminal is optimal for all the various users, it must be able to support various kinds of input terminals; (b) acceptable techniques for capturing free text information must exist; and (c) response must be rapid, since few medical professionals can tolerate delays of more than a few seconds for the information processing activities in their daily routines.

Output Requirements. Computer technology is advancing rapidly in output capabilities. Major limitations at present are high cost, noise, and lack of reliability of terminals. In addition, we understand little about man-machine communication of information. Perhaps instead of presenting information in text, we should develop the use of graphic or color presentations, or presentations in motion. The major requirements are flexibility in designing, formating, and experimenting with various kinds of output.

Storage Versus Processor Capacity. Most systems in university computer centers have large core storage and powerful central processor. They are aptly called "number crunchers," since the typical application involves predominantly numerical operations, such as the inversion of large matrices, with hundreds of thousands of additions or subtractions per second. In contrast, most patient care applications require relatively few numerical operations, but are more involved with the storage and retrieval of information. As a consequence, the usual large commercial system provides much more numerical capacity, a more powerful central processor, and a more complex operating system than is needed for patient care applications; the cost of such a system is therefore higher than necessary for these applications.

The technologic facilities for storing large data bases for microsecond or even millisecond retrieval are still limited and expensive. Of particular concern, until recently, few computers of modest size could support large volume, random access, secondary storage. The optimal system for patient care applications is one with moderate core storage capacity and central processor power, but an enormous amount of rapidly accessible secondary data storage. A system need not exist within a single computer configuration; rather, several

computers may be interconnected; and different functions, such as communication, control of terminals, and file-handling may be assigned to different parts of the system.

Text String Handling. Most commonly used programming languages, such as FORTRAN, BASIC, and COBOL, are grossly deficient in their ability to handle text string information. Only in the last few years have languages capable of manipulating text been introduced.

The necessary capabilities may be trivial, such as the recognition and extraction of a particular text string (for example, a name from a list of names) or the creation of narrative text from simple codes (e.g., the production of a narrative summary from the answers to a patient history questionnaire). The more sophisticated natural language processing capabilities and pattern recognition skills of the human being have not yet been emulated on a computer system. As a consequence, it is our belief that a major effort needs to be directed toward developing methods for capturing narrative information in a form that lends itself to further processing and analysis.[4,5] A promising approach to capturing text information from the physician, for example, is to use a branching question-answer dialogue between him and the computer.[6] This approach relies on a highly interactive terminal device and takes advantage of the patterned statements that the physician usually uses to describe particular ideas.

Data-Base Organization. A data management system for patient care requires a relatively complex organization for several reasons: (a) there is a wide variety of data types and formats; (b) the various entries in the files are interdependent. (Therefore, filing of data may involve simultaneous manipulation of several data fields. For example, the history of a drug reaction in the medical history section of a patient's record should be related to the data base referenced by a drug-ordering program.) (c) The file must be organized for rapid, easy access of specific sections only, as we are usually interested in a particular episode, a particular set of values, or a single consultant's note, rather than an entire patient record. Such a data base organization can be represented as a multilevel, multidimensional tree structure, permitting not only fields of various lengths, but also fields with an unpredictable number of values. On one day, for example, there may be only a single hematocrit reading, or a single x-ray report, but provision must be made to allow several such results in the same day. To deal with such a data structure, most file management systems have an unacceptable overhead, resulting in inefficient, slow access.

It cannot be too strongly emphasized that time response is critical in many situations of clinical data management, particularly where interactive

techniques are used. To achieve a rapid response by maximizing efficiency of storage and retrieval, special file management systems optimized for the specific characteristics of the problem and the data structure have to be designed.

Common Data Base. Perhaps the most important distinction between classic computer-based information retrieval systems and the newer data management systems is that the former are oriented toward a single user entering and retrieving information from a file, whereas the latter are not. In the classic systems, the file expands in a relatively predictable fashion. In data management systems, many users simultaneously enter and retrieve information from a common data base which is dynamically changing in an often unpredictable and chaotic fashion. In contrast to the traditional information retrieval systems, where user interaction is usually off-line, in data management systems the interaction is almost always through remote terminals scattered in different locations and serving a variety of functions for a variety of users. For example, in a patient care data management system, the central data base entry regarding patient location might be modified by information entered via a terminal either in the admissions office (scheduled admission), on the care unit (for a patient transfer), or in the emergency ward (an emergency admission). Current location information must be simultaneously available to terminals in the clinical laboratories (regarding source of specimens and destination of results), in the pharmacy (providing locations to which drugs should be delivered), and in other parts of the hospital.

The central data base concept is essential for a system to be used in real-time hospital operations, to prevent conflicts in scheduling. When an x-ray department attempts to schedule a barium enema, for example, all possible conflicts with other patient activities must be resolved. Another illustration of the use of a common data-base is for medical auditing activities; an example might be the recording by a physician of a particular physical finding, such as a type of skin rash, and the initiation by the system of procedures that can examine the patient's drug orders to determine whether this skin rash could be a side effect of one of the agents received by him. This use of multiterminal multipurpose access to a common data base is still to a large extent conjectural, since to our knowledge, most computer-based patient care systems are still primitive and do not take advantage of these possibilities. However, the potential is real; and planning for the interaction and interdependence of the central data base with the real-time entry and retrieval of data from many remote terminals is a complex, intriguing medical and technical challenge.

Programming Languages. The design criteria that have been elaborated upon thus far may be considered to be characteristic of the problem area itself. While it remains true that almost any task that can be specified can be implemented on a computer, most computer systems are not so designed that it is easy to develop applications requiring these features. These capabilities are complex, and execution of programs involving their use requires the performance of large numbers of operations. It is only when these subordinate functions can be automatically carried out as a consequence of merely specifying the task itself, that these features may be considered to be truly available to the user.

Thus we would emphasize the need for high level languages in which various command words and statements are provided for performing the variety of tasks required for patient care data management. These programming languages should be relatively easy for the non-"computernik" to understand, in order to facilitate the direct participation of subject matter experts in the development of applications.

Much of the original impetus for the development of such languages comes from the desire to reduce the dependence on expert computer programmers, and to make it possible for individuals concerned with real-world problems to use the computer directly for their solution. One of the important factors limiting introduction of computer technology into medical care applications is the need for a cadre of systems analysts and programmers to translate problems into a form suitable for computer processing.

Although we have not yet realized the dream of a computer language that can be used easily by persons lacking computer expertise, we do know some of the characteristics such a language should possess. (a) It should be procedural; that is, the command structure should have a close symbolic relation to the activities to be carried out; e.g., there should be equivalent verbs to "schedule," "retrieve," "medicate," etc. (b) The language should allow easy modification of programs, since an overwhelming characteristic of medical applications of computers is that both objectives and procedures change and evolve with time. (c) The language should be self-documenting; i.e., the functions carried out by the program should be apparent from the language in which they are expressed. The management of a programming group and a large project is arduous, and the more primitive the language, the more difficult the management. (d) The language should have a rich vocabulary of diagnostic messages to guide the user in recognizing and correcting his errors. In any programming task, the initial design and writing are often straightforward; the harder and more tedious task

is detecting the minor bugs that, though trivial, can create absolute havoc. (e) The language should not require excessive obedience to artificial conventions and trivial rules. This is not to say that ambiguity can be accepted; a significant benefit of using computer technology derives from the need to define objectives, strategies, and procedures in explicit terms, without intrinsic contradiction. But this must be a comfortable and simple process, so that the primary concern does not become the nuances of the language, but the important issues of the problem area.

Modular Implementation. Traditionally, most health care facilities have not desired, nor been able, to initiate computer developments on a large scale with large financial commitments. The computer system development must be on a modular basis, with the initial efforts on a relatively modest-sized computer configuration. The project must focus on providing realistic service now, rather than developing some total system for the future. The language and the computer system must have the flexibility and the power to support modular implementation, yet also permit graceful evolution to larger, more ambitious objectives.

In a symposium such as this, a discussion of high level programming languages must be put in proper perspective. A major limiting factor in the rate of introduction of computer systems into patient care applications has been the growing pains of learning to use computer technology; but this is not the only limitation, and probably not even the most important one. It is our impression that much more important issues are the characteristics of the power structure and priorities of the health care establishment, the mechanisms for deciding which costs are reimbursable by whom, the habit patterns and role perceptions of the physicians and nurses, and the complexity of the ill-defined and often conflicting objectives of patient care.

Undoubtedly, good computer systems and powerful programming languages will be useful. However, the definition of design criteria for computer systems and the development of appropriate high level languages are tasks which seem to be orders of magnitude simpler than any similar radical innovation in the health care delivery system.

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ACQUISITION AND ANALYSIS OF NARRATIVE MEDICAL RECORD DATA

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INTRODUCTION

Research in the application of natural language data processing techniques to patient record information was started at the Bowman Gray School of Medicine in the fall of 1965. This research effort has resulted in the development of "batch" and "on-line" techniques for acquiring narrative text and for the subsequent data screening, editing, and information retrieval operations. The data files currently contain approximately 350,000 documents and new material is being entered at the rate of approximately 75,000 reports per year. This paper describes the acquisition, screening, and editing sections of the natural language data processing system.

NARRATIVE DATA ACQUISITION SYSTEMS

At the present time, there are potentially four basic techniques for the acquisition of narrative text data: speech analysis, optical character reader, typewriter, and optical display terminal. Speech analysis may represent the ideal approach in that it would enable the physician or other member of the health care team to report medical information by "conversing" directly with the data processing system. Speech analysis systems have been under development for many years but, as yet, none has reached the level of sophistication that is required. It is theoretically possible to develop such a

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system and, if the cost is not prohibitive, this may represent a practical approach in the future.

Optical character readers have been significantly improved in recent years and do represent one practical method for acquiring narrative text data. The systems are used successfully for scanning airline ticket stubs, finance vouchers, and a variety of other documents. The currently available systems have, however, some significant limitations. The first is cost. The lease prices for an appropriate optical character reader range upward from approximately $2,700 per month and the service bureau charges for processing documents are typically in the range of 1 cent for each line that is scanned. In single-spaced documents, page registration can be a very critical factor. It is not unusual for small amounts of horizontal skew to cause the optical character reader to jump incorrectly to the line above or below the one being scanned. In practice, even with the use of sprocket fed paper it is difficult to maintain the required page alignment. The printed characters must be distinct; smudges, partial erasures, and other distortions can cause read errors. Some optical character readers cannot handle colons, semicolons, equal signs, and other standard characters. Many readers require the use of nonstandard characters or special document formats. Finally, this approach to narrative text data acquisition typically provides little if any editing capability at the time of preparation of the source document. At present, this approach is thus most practical in those applications in which the input volume is high, the document layouts can easily be formated and there is little requirement for editing at the time of data entry.

The principal components of the optical display terminal are a keyboard similar to that of a standard typewriter and a cathode ray tube for displaying the characters. It is possible to design a "stand alone" system in which an optical display terminal is interfaced directly to magnetic tape or some other digital storage system; however, the terminal is usually used for the "on-line" communication of information to and from a computer system. The primary advantages of this approach are that the user is provided with excellent data editing capability and, through the computer system, is able to take advantage of information retrieval and other programs. The primary disadvantages are that the system is dependent on the availability of a reliable computer system, and that the majority of the terminals are relatively expensive.

Three basic typewriter systems may be used for narrative text data acquisition. First, the typewriter may be connected directly on-line to a computer. This configuration has two disadvantages: the system lacks the display editing and transmission capabilities of the optical display terminal and

is dependent on the computer. A second approach is to connect two or more typewriters through a small computer to a magnetic disk or other shared storage system. Several companies are now marketing this type of data acquisition system. The primary advantages of this approach over a conventional medium to large scale computer system are that the small computers are relatively inexpensive and, in general, are highly reliable. In the future, these "cluster" systems may prove to be the least expensive and most practical of the typewriter to magnetic media data acquisition techniques.

Finally, there are the "stand alone" systems in which a single typewriter is connected to a magnetic tape drive. A large number of manufacturers are now producing systems of this type. They range in complexity from a keyboard that is interfaced directly to a magnetic tape drive up to systems which have sophisticated editing capabilities.

Amongst the many possible data acquisition systems, the Magnetic Tape "Selectric" Typewriter (MT/ST) was selected for use by our group. This system consists of a high quality office typewriter which is interfaced to a pair of magnetic tape drives. It has a number of features which make it well suited for narrative text data acquisition operations. Errors noted during typing are easily removed by backspacing and retyping. "Tape to tape" operations are possible, allowing any amount of data to be added or deleted from a tape record. One tape may be used to generate standard headings which can be simultaneously printed and recorded on the second tape. This latter feature serves a dual purpose of relieving the secretary of some typing and of forcing replies when the headings are in the form of a questionnaire. An additional system feature is that individual documents may be located on a tape by means of a search code system.

The MT/ST magnetic tape cartridges are not directly computer compatible, and, as the system was originally marketed, no provision was made for the transfer of data to a computer. Circuitry for interfacing the MT/ST to a stepping digital magnetic tape recorder was developed in July, 1966, at which time the system was first used by our group for entering narrative text data for computer processing. Interface circuitry was subsequently developed for connecting the MT/ST system directly on-line to a general purpose digital computer.

Data could thus be transferred either to the stepping digital magnetic tape drive or directly on-line to the computer system by using the playback mechanism in one MT/ST typewriter. This system uses a single-track magnetic tape head which is mechanically stepped across each of the nine data tracks on

the tape. The mechanics of this system limit its data transfer rate to a maximum of approximately 20 characters per second. This rate can be markedly increased by the use of a nine track "in-line" magnetic tape head. Several different manufacturers now produce high speed readers of this type which are capable of transferring the digital data from the MT/ST tape cartridges either on-line to a computer system or to a standard computer compatible magnetic tape drive. Systems for interfacing the MT/ST directly to a stepping digital magnetic tape drive, a modem, or on-line to a computer system are also currently commercially available. Figure 1 shows the MT/ST and one tape conversion system.

Figure 1. Magnetic tape Selectric (MT/ST) typewriter and stepping digital recorder tape conversion system.

DATA ENTRY USING THE MT/ST SYSTEM

Incoming reports are first dictated in a conventional manner by members of the medical staff. The only restriction is that the staff is encouraged to follow a fixed sequence and to comment on all the required items of information. The incoming medical documents are transcribed as follows: the headings for each of the sections in the report are prerecorded on a master tape. This tape is then loaded on one of the two MT/ST tape drives and a blank tape is placed on the other. The system automatically searches to locate the start of the master tape. Actuating the start button causes the first paragraph title to be typed out and to be automatically transferred to the output data tape. The secretary then types in the appropriate commentary for this particular section of the document, obtaining the required data from the dictated material. Errors noted at the time of typing are corrected by backspacing and retyping. On completion of a given section, the start circuitry is again actuated and the system automatically reproduces the next section title. It is not necessary to use the master tape in this manner; however, the operation is of value in that the secretary is relieved of typing the titles and the omission of information is reduced.

After a given document has been typed, the secretary proofreads the draft copy and makes any final corrections by editing the MT/ST tape. The final copy is then typed out automatically by the MT/ST from the corrected tape. Document format and length are not restricted; however, the narrative text must conform to the rules of English grammar.

In using the MT/ST system, one question that should be considered is the effect of the error correcting ability on document production rates. This problem has been investigated by a number of different groups. Published studies have indicated document production rates that range from less than to more than double those obtained with a conventional office typewriter. It has been our experience that document production rates depend on the following principal factors: nature and quality of dictation, skill of typist, error correction policy, number of copies, editing requirements, and need for retyping. They also depend on the contact and rapport between the dictator and the typist. For example, a private secretary who works consistently with the same limited group of physicians rapidly becomes accustomed to their dictating style and is able to transcribe material much more efficiently than is the typist in a pool that serves a large number of different individuals.

Surgical pathology reports are typically concise, carefully worded and

consistent in format. Our experience with the entry of documents of this type has been that the secretary rarely is required to change the wording of the original dictation and that the material can be transcribed with a very low error rate if the typist is skilled. It is rarely necessary to retype an entire document or to erase an error on multiple carbon copies; thus use of the MT/ST cannot significantly reduce the time required for typing the documents.

Time-motion studies have been carried out on the various steps that are involved in the entry of surgical pathology reports. Table 1 presents information on the time required and the cost of the initial transcription, error

Table 1.–Document data entry time and cost for the MT/ST system

Operation	Time	Cost
	(Min)	$
Transcription	5.57	.43
Error correction	.71	.05
Printing	2.91	.22
Total	9.91	.70

correction, and printing operations. The reports vary in length from one-half to two pages with an average of three-quarters of a page. The transcription time for an "average" document is 5.57 minutes. Error correction by backspacing and retyping takes an additional .71 minutes. The final, corrected copy of the document must then be printed out by the typewriter. The typing speed is 15.5 characters per second; however, a significant amount of time is still required for the printing operation. In contrast to this approach, Table 2 presents the transcription and error correction time for a conventional office typewriter. The error correction time is increased; however, the overall time is decreased because it is not necessary to print the document. The error correction time will markedly increase with a poor typist, especially if it is necessary for her to retype an entire document.

Table 2.–Document data entry time and cost for a conventional typewriter system

Operation	Time	Cost
	(Min)	$
Transcription	5.88	.29
Error correction	1.28	.06
Total	7.16	.35

Table 3 summarizes the differences between the conventional and MT/ST typing systems. It is obvious that if no "after the fact" corrections need to be made and the typist is skilled, use of the MT/ST system cannot increase document production rates. The MT/ST system does, however, have a great advantage over conventional typing in any circumstances in which it is necessary to edit and retype a document or when the keystroke error rate is high. It has also been our experience that all of the secretaries enjoy using the MT/ST system and that, because the concern over making occasional errors is virtually eliminated, the keystroke rate can be increased and there is less stress associated with the typing operations. Finally, the error correction ability of the MT/ST system is a very important feature; however, the prime reason for

Table 3.–Summary of differences between MT/ST and conventional office typewriter data entry times and costs.

Item	Manual	MT/ST	Difference
Transcription time*	5.88	5.57	- 5.2%
Error correction time*	1.28	0.71	-44.5%
Printing time*		2.91	
Cost**	.35	.70	+50.0%

* Minutes

**Dollars

using this system is that the data contained in the documents are acquired for computer processing at the time that the document is typed. The need for secondary transcription is thus completely eliminated.

INITIAL DATA PROCESSING OPERATIONS

Data stored on the MT/ST tapes are entered for computer processing either directly on-line or through the intermediate step of generating a computer compatible magnetic tape. The following data processing operations are then performed: formating and header generation, data screening, volume analysis, abstracting, and file maintenance.

On entry for computer processing, the narrative text is first "packed" so that each word and most punctuation marks are preceded by a binary character count. This count is required in all subsequent "word matching" data processing operations. It is also of value in providing a constant check on the integrity of a record.

A number of routine file operations are greatly facilitated by the location of the controlling data in a fixed field area. For this reason, a 21-word header is located at the beginning of each of the variable length text records. The header contains special identification information which is obtained automatically by scanning the input text and extracting the data of interest.

On completion of these initial data formating steps, the narrative text is passed through a number of screening operations. The first is spelling analysis. Correct spelling is essential both for maintaining high quality documents and for minimizing errors in information retrieval operations which are dependent on word matching. In the current spelling analysis operations, the words in the incoming reports are first read in from the "packed" data tapes and are then sorted in alphabetical order. This alphabetical list is next matched against a master vocabulary.

The text of the report is printed, followed by a list of all those words not found in the vocabulary. These same words also appear in dark type at all locations in which they occur (Fig. 2). This latter operation is achieved by maintaining a key which gives the location of each word, then overprinting those words not found in the vocabulary, thus facilitating location of the questionable words in the text.

The results of the spelling analysis are reviewed by the medical secretary who originally typed the document. Misspellings in the list of words at the end

```
'ID'351.
NAME:  MR.  C.  L.
LOCATION:  2 R.  HOSPITAL NUMBER:  11 22 33.
PHYSICIAN:  S.  E.  W.  ACCESSION:  MR - 67 - 0161.
DATE RECEIVED:  05 - 03 - 67.
SEX:  MALE.  BORN:  01 - 01 - 47.  RACE:  WHITE.
TISSUE SUBMITTED:  APPENDIX.
CLINICAL SUMMARY:

20 YEAR OLD PATIENT.  IMPRESSION:  ACUTE APPENDICITIS.

GROSS ANATOMIC FINDINGS:

AN APPENDIX, 6.2 CM. IN LENGTH IS ROUGHLY FUSIFORM IN
SHAPE, AT ITS MID POINT BEING 1.6 CM. IN DIAMETER.  AT
THIS POINT, THERE IS A TAN EXCRESENCE EXTENDING 0.3 CM.
ABOVE THE LEVEL OF THE APPENDICEAL WALL THAT IS TAN IN
CONTRAST TO THE BLUE-GRAY OF THE ORGAN AS A WHOLE.  THE
LUMEN FOCALLY IS DILATED TO 0.8 CM. IN DIAMETER AND
CONTAINS BROWN FRIABLE MATERIAL.  4 BLOCKS.

MICROSCOPIC FINDINGS:

THE EXCRESCENCE NOTED GROSSLY IS COMPOSED OF FAT THAT
LIFTS THE SEROSA.  THE WALL OF THE ORGAN IS WITHOUT
EXUDATIVE CHANGE.  THE LAMINA PROPRIA INCLUDES AN
INCREASED NUMBER OF POLYMORPHONUCLEAR CELLS.

INTERPRETATION:

EARLY ACUTE APPENDICITIS WITH DILATATION.

PATHOLOGIST:  W.  J.  R.  ##.


          6       SUSPICIOUS TERMS
EXCRESENCE                0000                    0000
**************************************
    2656    0    0    0    0    0    0    5    3    67
       0    0    0    0  MR   351   67  161    0     6
**************************************
```

Figure 2. Example of spelling analysis.

of each report are readily located within the text by scanning those words that appear in dark type. These words are corrected by editing the original MT/ST tape or by using a video data terminal which is on-line to the computer system. The vocabulary is updated daily with all the new words detected by spelling analysis.

Spelling analysis is a relatively unsophisticated operation in that there is no check of whether or not the words are appropriate to the context in which they are used. Words that are correctly spelled but incorrectly used, thus go undetected. No current program provides automatic screening for either syntactic or semantic errors. These latter operations would certainly be desirable. Some progress has been made in this area by the many investigators working in the field of linguistics; however, no satisfactory solution of this type of narrative text screening is available at the present time.

Each word in the master vocabulary is identified as to parts ofspeech, facilitating some analysis of the content of the sentences and phrases within the text. Investigations of the more sophisticated syntactic and semantic analyses are in progress and those approaches that prove to be of practical value will be incorporated into the data screening operations. Currently, a check is made for these errors both at the time the secretary proofreads the original draft of the document and again when the results of the spelling analysis are reviewed. In spite of its limitations, the currently available spelling analysis procedure has proved to be highly useful. This check has resulted in the detection of a significant number of misspelled and misused words. At present, approximately 15 percent of the reports being processed contain one or more spelling errors.

Actual misspellings are the result of incorrect assumptions on the part of the secretary or of typographical errors. The incidence of typographical errors is small as a result of both the error-correcting procedures of the MT/ST and the medical secretary's diligence in proofreading the documents and making the appropriate corrections. During the early phases of the operation, it was noted that a number of words were chronically misspelled. The fact that the medical secretaries receive the results of the spelling analysis and then make the corrections in their own typing, has been invaluable in teaching them correct spelling. An effect of the feedback of information from the computer system to the medical secretaries has been rapid elimination of most chronic misspellings.

The master vocabulary is maintained in several different forms. The version utilized for the spelling analysis contains an alphabetical listing of all words that have appeared in any incoming document and the parts of speech of these

words. Another version of the vocabulary provides information on the frequency of occurrence of each word. These frequencies were computed by sorting the words in the entire document file in alphabetical order, then computing the frequency of occurrence of each word. This listing is updated weekly as new documents are entered into the system, thus providing a continuous record of word use. The frequency data are broken down by report type; thus it is possible to selectively review the vocabulary of the pathologist, surgeon, or other medical specialist. These data are of value in basic studies of medical linguistics, in evaluating medical education, and in teaching medical terminology.

The scope of the vocabulary has been one of the more interesting findings to date. A standard medical dictionary contains approximately 500,000 different terms. Doctor Baldwin Lamson[1] at the University of California reported finding approximately 9,500 different words in the conclusion section of surgical pathology reports processed over a 5-year period. At this institution, we found approximately 9,000 different words in scanning the same section of surgical pathology reports over a 4-year period. When data processing operations were widened to include discharge summaries, operative notes, and other medical documentation, over a 3-week period the vocabulary increased from 9,000 to 20,000 words. At the present time, there are approximately 40,000 different words in the master vocabulary. These were generated from a consolidated medical record file which contains more than 10,000,000 words. Table 4 provides a listing of the frequencies of occurrence of some of the more common terms encountered in the surgical pathology reports.

Table 4.–Common terms used in surgical pathology

Incidence	Word	Incidence	Word
200416	OF	68250	BY
126006	AND	64605	IN
120237	THE	55057	MALE
108379	A	47002	SKIN
106983	FEMALE	43069	TO
96239	WITH	40285	RIGHT
80740	TISSUE	38923	LEFT
74837	IS	37657	CHRONIC
72703	FROM	34764	CELL

The limited size of the vocabulary, while an unexpected finding, greatly facilitates a number of the natural language data processing operations. Information retrieval operations are both simpler and less subject to error with a relatively restricted vocabulary, and the spelling and other screening operations can be carried out at high speed. The rate of growth of the vocabulary has leveled off; however, it can be expected to continue to increase in size both with the advent of new words in the language and the gradual inclusion of the rarer terms that are in current use. Although it will somewhat complicate future data processing operations, a vocabulary of 500,000 or more words is well within the capabilities of current technology.

In the analysis of the actual content of the documents, the reports are first screened to determine whether or not selected control words are followed by an appropriate response. The exactness of the check depends on the complexity of the data. For example, SEX can only be followed by "male" or "female"; whereas any text other than a blank or "unknown" is accepted following ADDRESS. An extension of this technique is a check for multiple items which must be listed under a general heading.

In its present form, the screening operation is primarily of value only in detecting omissions and certain very obvious inconsistencies. The program is able to confirm the presence of specific commentary but does not determine its appropriateness within the context of the report. Investigations in progress have revealed that it is practical to perform much more sophisticated content analyses. One approach that has been employed is to store within the computer system textbook information on the data being scanned. This information then makes it feasible to "look up" a final diagnostic impression and to compare the microscopic and gross findings of the report with those indicated in the reference material. This approach has been tested using information available from an abbreviated medical text, *Current Medical Terminology*,[2] and from a drug compendium. Experience with these texts has demonstrated that they are useful both for the content screening operation and as a reference library for the physician.

On completion of the various screening operations, the incoming reports are merged into one or more data files. Special subfiles are generated simultaneously. For example, selected sections of all incoming reports are automatically screened for series of words and phrases indicating a diagnosis of malignant neoplasia. When one of these terms is found, the sentence in which it occurs is printed out together with the patient's name, number, and the date of the report. A running count is also maintained on the number of different

types of malignant neoplastic disease found while processing a group of reports. After the data file has been screened, a summary of the types and percentages of cancers found is printed. A subfile consisting of all those reports in which malignant neoplasia was detected is also generated automatically at the same time as the screening operations. This same basic technique may be used to generate any number of other special files. Examples of the output from the cancer data screening operations are presented in Figures 3 and 4.

On completion of all of the data screening, editing and file updating operations, the data are made available to the user through a general purpose information retrieval program. Information retrieval requests are established through a question and answer "conversation" between this program and the requester. The files of interest are scanned and the requested data are displayed on one of the on-line video data terminals or are printed on a high- speed line printer.

TUMOR REGISTRY

REPORT TYPES... SURGICAL PATHOLOGY
REPORT DATE.... 10-25-68

INDEX	NAME	NUMBER	DATE	INCIDENCE	NEOPLASIA
1	C*C*	348812	050267	1	NEUROFIBROMATOSIS.
2	C*S*	453177	050267	1	MESOTHELIOMA OF EPIDIDYMIS.
3	W*O*	391907	052367	1	SQUAMOUS CELL CARCINOMA
4	C*M*	281543	052267	1	INTERPRETATION: MODERATELY DIFFERENTIATED ADENOCARCINOMA METASTATIC TO LYMPH NODE.
5	V*G*	396457	052367	2	SQUAMOUS CELL CARCINOMA OF SKIN FROM 'LEFT SIDE OF NOSE,' ADEQUATELY EXCISED.
6	E*C*	005091	052367	1	BASAL CELL CARCINOMA OF THE ANTERIOR ASPECT OF THE NOSE.
7	R*C*	398275	052367	3	SQUAMOUS CELL CARCINOMA, POORLY DIFFERENTIATED, PREDOMINANTLY INTRAEPIDERMAL, OF SKIN FROM 'LOWER BACK'.
8	W*H*	203780	052367	4	SQUAMOUS CELL CARCINOMA, MODERATELY DIFFERENTIATED FROM 'LIP'.
9	E*B*	453059	052267	2	INTERPRETATION: WELL DIFFERENTIATED ADENOCARCINOMA OF GALLBLADDER.

Figure 3. Tumor registry abstract.

NAME....SURGICAL PATHOLOGY
DATE.....10-25-68

NEOPLASIA	TOTAL	PERCENT NEOPLASIA	PERCENT SCANNED
1. BASAL CELL CARCINOMA	2	4.88	2.00
2. SQUAMOUS CELL CARCINOMA	9	21.95	9.00
3. MALIGNANT LYMPHOMA	2	4.88	2.00
4. MALIGNANT MELANOMA	1	2.44	1.00
5. TRANSITIONAL CELL CARCINOMA	1	2.44	1.00
6. GIANT CELL TUMOR	1	2.44	1.00
7. CARCINOMA	12	29.27	12.00
8. CANCER	4	9.76	4.00
9. METASTATIC	2	4.88	2.00
10. ADENOCARCINOMA	4	9.76	4.00
11. MESOTHELIOMA	1	2.44	1.00
12. TERATOMA	1	2.44	1.00
13. NEUROFIBROMATOSIS	1	2.44	1.00

TOTAL RECORDS PROCESSED	100.00
TOTAL REPORTS OF NEOPLASIA	41
TOTAL PERCENT NEOPLASIA	41.00

Figure 4. Tumor registry statistical summary.

Table 5 presents a summary of the current times and costs for the initial narrative text data processing operations. It should be noted that document screening requires the most significant amount of time, 13 seconds. This time can be expected to increase as the data screening operations are expanded and become more sophisticated.

Table 5.–Document data processing time/cost

Operation	Time	Cost
	(Min)	$
Tape to tape conversion	7.6	.01
Formating and labeling	2.7	.09
Screening	13.0	.43
Volume analysis	3.4	.11
Abstracting	1.7	.06
File maintenance	8.4	.28
TOTAL	36.8	.98

DISCUSSION

The experience of the past four years has clearly demonstrated that the MT/ST system provides a practical means by which narrative text reports can be acquired for computer processing and that a variety of techniques are available for screening and analyzing the natural language data. It is important to now consider the limitations and benefits of these data handling operations.

Extensive experience with surgical pathology reports has demonstrated that concise, well formated documents of this nature can be easily screened, analyzed, and retrieved using natural language data processing techniques. It has not been possible to obtain the same results with admission histories, discharge summaries, and other similar documents because of their complexity, length, and typical lack of organization. Three basic techniques for improving the quality of the latter types of document have been under investigation. First, Doctor Lawrence Weed's[3] "problem-oriented" record is being explored as a means of organizing the information in a consistent and medically logical manner. Second, computer-based interviewing techniques are used to provide data to supplement information obtained by the physician. Finally, advanced methods for screening the content of the incoming data and providing feedback concerning missing or inconsistent information are under investigation. All of these approaches have advantages and disadvantages. It appears likely that a combination of them will be employed in the future for the acquisition and organization of medical record data.

One fundamental question yet to be resolved concerns the relative merits of narrative text compared with the structured, computer-directed questionnaire. The questionnaire insures that all questions felt to be pertinent are asked, and provides a means of presenting the data of interest to the computer system in a compact, fixed format. Responses can be examined for consistency and questions rephrased if it becomes obvious that the subject failed to understand the question or made a mistake. It is also possible to evaluate the pattern of the responses, to compute diagnostic probabilities, or perform other analyses. A disadvantage of this approach is that it is usually necessary to ask a large number of questions and that entry of replies is time-consuming and tedious. It is also difficult to describe gradations in findings or exceptions, or to present a chronologically oriented discussion of a given problem. A number of investigators have reported good results with computer-directed interviews of patients.[4,5] The typical findings have been that the patients usually enjoy participating in a computer-based interview; that the information obtained is

frequently more accurate and more comprehensive than that reported by the physician, and that patients reveal facts of a personal nature that they may be unwilling to mention to their physician.

In addition to the above considerations regarding the nature of the medical information that is to be processed, there are also some unresolved problems involving natural language analytic techniques. No general parsing methods have been developed, and current syntactic and semantic analyses are very unsophisticated. The magnitude of this problem is demonstrated by the fact that, in spite of the considerable effort invested in language translation programs, a practical translator has not been developed at this time. Much work thus remains to be done in the area of improving the techniques for screening the content of the narrative text. There is also an urgent need for the development of methods for abstracting and summarizing significant items of information embedded at various locations within a series of narrative medical reports.

Finally, there is a question of the value of the data processing operations. The primary benefits that can be expected are quality control, education, abstracts, information retrieval, and administrative functions. The quality control operations that are possible can materially assist in insuring that the medical information reported is both accurate and complete.

The natural language data processing operations have considerable educational potential deriving from the feedback to the medical staff of information on omissions, inconsistent data, and a variety of other errors. Automatic abstracting of information, as has been illustrated by the tumor registry data processing operations, reduces or eliminates time spent on this task by the medical staff. Also, a number of studies have demonstrated that computer-based data screening operations can be significantly more accurate than those normally carried out by members of the medical staff. Information retrieval operations provide immediate access to specific medical reports, and can scan large files to find those reports that contain a series of items of interest. Finally, as a useful by-product, natural language data processing operations can perform patient billing and a variety of other administrative functions.

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VISUAL DISPLAY TERMINALS

IN A HOSPITAL INFORMATION SYSTEM (HIS)

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INTRODUCTION

In the last few years the concept of an automated information system for use in medicine has gained increasing attention. The use of such a system in a hospital is especially attractive because of the rapidly increasing costs of modern hospitals and the large fraction of the cost involved with information.[1]

While a number of problems exist in implementation of such a system, one of the most difficult has been that of man-machine communication. The visual display terminal represents the most satisfactory approach to a solution that is yet available. [2,3]

It is the purpose of this paper to discuss strategies for utilizing visual displays in a hospital information system.

HARDWARE

The Hospital Information System is a computer-based one in which a central computer drives multiple terminals throughout the hospital. A number of hardware configurations are possible; this discussion will be limited primarily to that being developed for Kaiser Foundation Hospital in San Francisco. The over-all system configuration has been described previously.[4]

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The visual display terminals, designed by Sanders Associates, are to be placed throughout the hospital in a distribution corresponding to the expected load on the terminals. The present complement of 24 terminals represents approximately half the number that would be required if most of the important medical functions were to be implemented in this approximately 300-bed hospital.

Each terminal (Fig. 1) consists of a cathode ray tube display unit, a "light pen" connected to the display, a typewriter-like keyboard, a small card reader, and a printer enclosed in a soundproofing box. The display unit is capable of displaying approximately 1000 characters in an area approximately 10" by 7". The display consists of 40 lines of 52 characters. Only half the total character positions may be visible for a given display.

PROGRAMMING – ILLUSTRATION OF SIMPLE STRATEGY

Displays seen at terminals are under control of programs running in the small central computers, a Honeywell 516 and Honeywell 416. Programming is done in a file-oriented, higher level language, FOPS (*F*ile *O*riented *P*rogramming *S*ystem). FOPS is a multiprogramming, list processing, virtual memory, interpretive system similar to the MUMPS system employed at the Massachusetts General Hospital.[5]

Data are organized into *files;* each file may have any number of *subfiles,* and each subfile may have many *pages.* A page corresponds to what is seen on the screen of a visual display. Each page has a corresponding form or overlay. The process of constructing a display consists in displaying a form, which may be blank or highly structured; then filling in the corresponding blank parts from the page.

The strategy of using forms is useful in conserving storage space, since the same displays, with only minor changes, are often used many times.

Figure 2 shows a simple form that might be used in admitting a patient to the hospital. The form is displayed on the visual terminal. The blank parts are indicated by dots. A clerk may now fill in the blanks by typing the information on the keyboard. While this may seem identical to typing on a paper form, certain differences should be noted. Skipping a line on a typewriter involves using special controls such as a carriage return. Similar controls appear on the terminal keyboards, but their implementation is more involved than on a typewriter, since unlike a typewriter carriage, these controls do not always return to the same starting point.

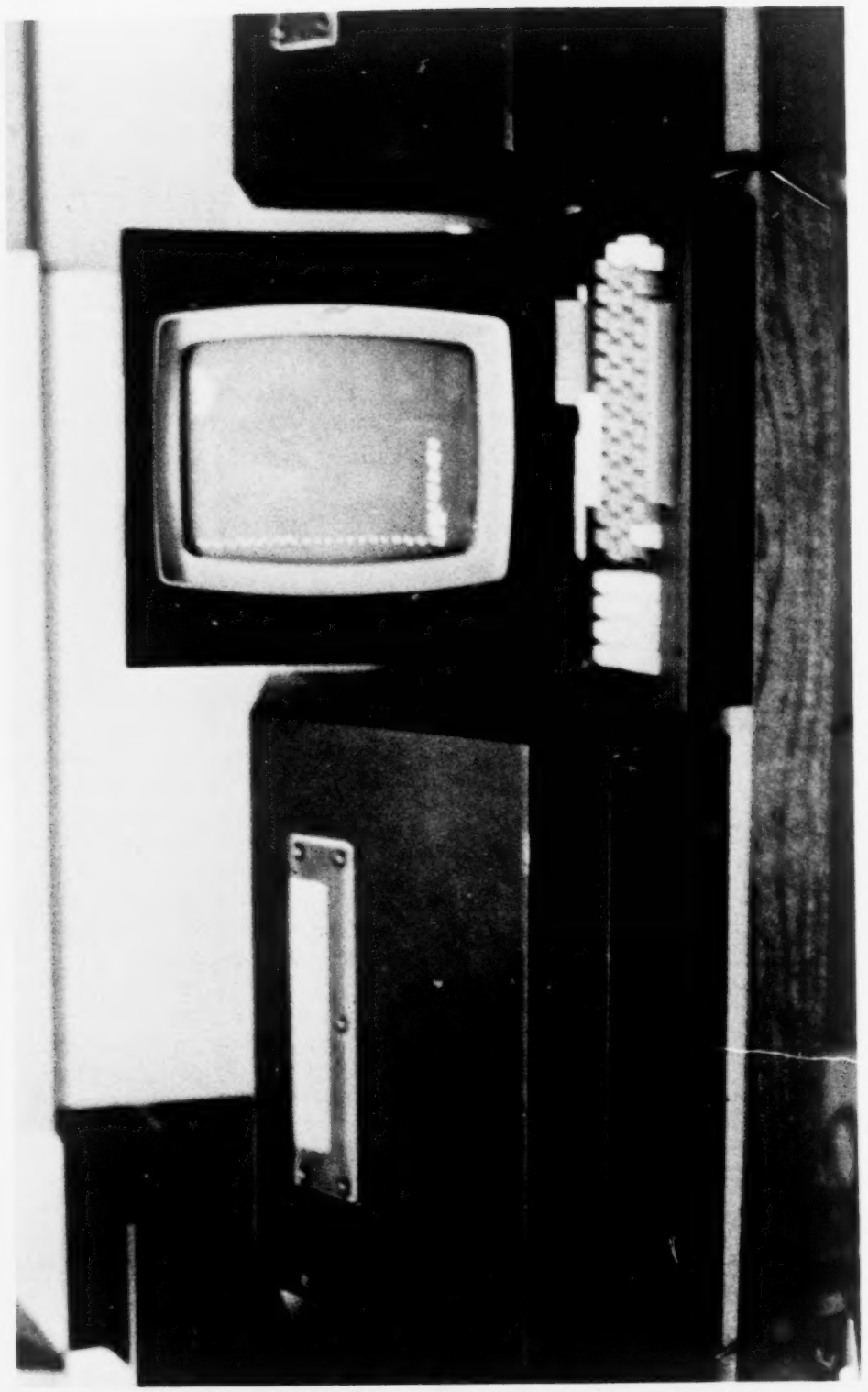

Figure 1. A view of the terminal.

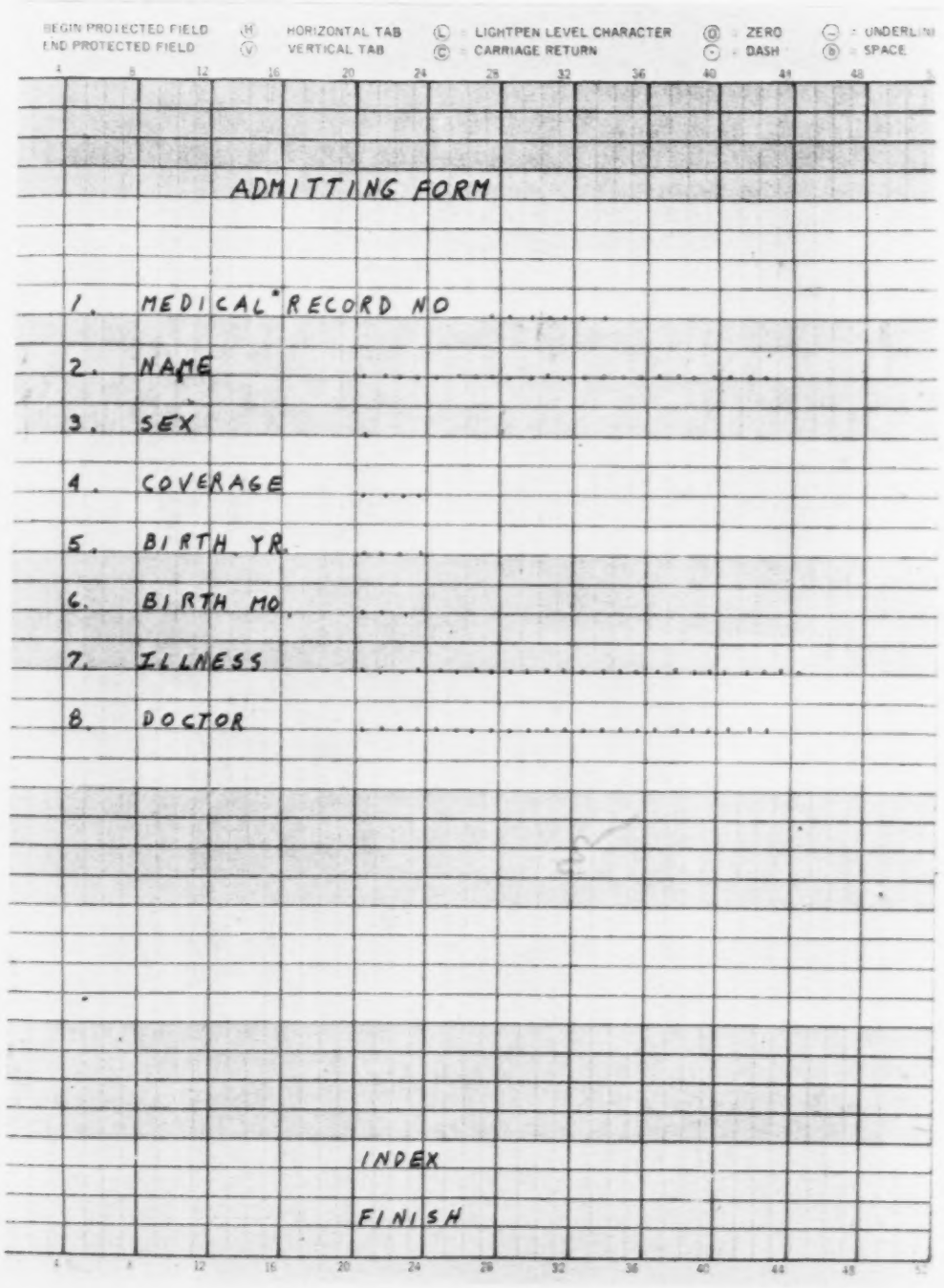

Figure 2. A sample admission form.

A second problem is error correction. One cannot roll the paper back in a display terminal and erase the error. One may touch the erroneous entry with the light pen, thereby signaling the computer that the entry is to be corrected. Or one may type the number of the entry to be corrected at the end of the entry sequence, then type the correction. The strategy illustrated in Figure 2 is both incomplete and totally inadequate for a doctor wishing to enter an order or diagnosis.

PHYSICIAN INTERACTION WITH VISUAL TERMINALS

Several steps are logically required to input information into a hospital information system:

1. Identification of the user to the system
2. System acknowledgement
3. Selection of a patient or patients
4. Input of information to the terminal
5. Verification that information is correct
6. Printing of the information.

Because the system is large, involving many people and privileged information, it is necessary to restrict the functions of its users. An admission clerk may not write a drug order. A doctor will not generally change computer programs. These restrictions in use are accomplished by identifying the user by a machine-readable card. The system is activated by inserting into the reader on the terminal a card that identifies the user as an individual, and as belonging to a certain class. Various displays are available only to certain classes of user.

The system acknowledges a request for service by displaying the name of the user, the date, and time. This name, date, and time will be printed on every document printed by the user for that terminal.

Since most input transactions by physicians involve a single patient, or at least one patient at a time, the next step is identification of a patient followed by input of information about that patient, an order, a diagnostic statement, etc.

Finally the information is displayed back to the user for verification and correction of any errors. When correct, it is printed and placed in the hospital chart where it serves as backup in case of machine failure.

Examination of many different tasks has led to a fairly uniform functional layout for visual displays. Uniformity simplifies the process of training the user in using the system.

The basic format used in most display sequences (Fig. 3) contains a *heading* that identifies the user, patient, date and time, and may vary somewhat in content. Below the heading is a *status area* 4 lines deep. If the information to be entered exceeds 4 lines, the first part of the information is moved to another display called a "work page". The status area always contains the last four lines of information entered.

Below the status area is a title that identifies the display and indicates that a display may be one of a sequence. For example: "4 west census page 1"

The *body* comprises the largest part of the display; it contains information to be transferred to the status area, or may simply lead to another display.

At the bottom are commonly used *functions,* such as returning to an index, displaying the work page, paging forward or back. This portion is also used for certain common modifiers to be added to the status area.

The strategy developed for various tasks takes into account the functional limitations of existing terminal devices, but attempts to simulate as closely as possible techniques already familiar to the user. Displays are constructed so that the required information may be located with fewest steps and in the shortest possible time. This generally involves two familiar techniques, multilevel indexing and the use of prestructured common information. The drug-ordering sequence that follows illustrates both concepts.

A DRUG-ORDERING STRATEGY FOR VISUAL DISPLAYS

The drug-ordering sequence starts with identification of the doctor from his card. Upon reading the card the terminal displays a list of patients logically associated with that terminal (Fig. 4). This will usually be all patients at a given nursing station.

The doctor selects a patient by light-penning a name. The name is transferred to the heading area and a general index is displayed (Fig. 5). A class of order may then be selected from the list shown under the heading, "Orders". The most general case is selection of a drug from an alphabetic list of all drugs. This is accomplished by light-penning "Alpha Index".

Because many pages of drug names are available, the names are stored in alphabetic order and selection Alpha Index causes the display in Figure 6 to appear.

Light-pen selection of the first letter of the drug name causes the first page of drugs starting with a given letter to appear. Figure 7 illustrates the first page of drug names starting with A. If the drug desired is not on the page displayed,

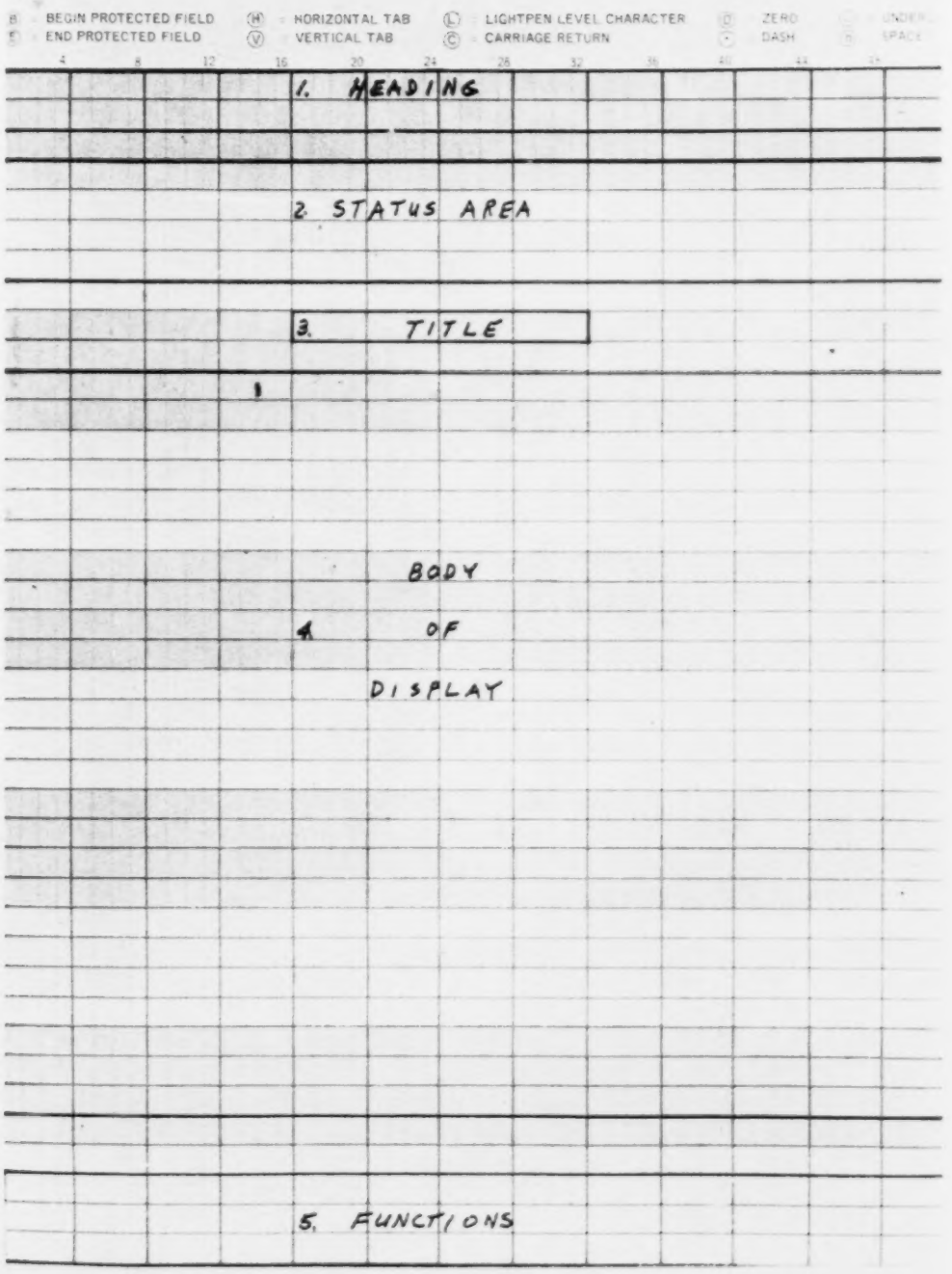

Figure 3. Basic display format used for most displays.

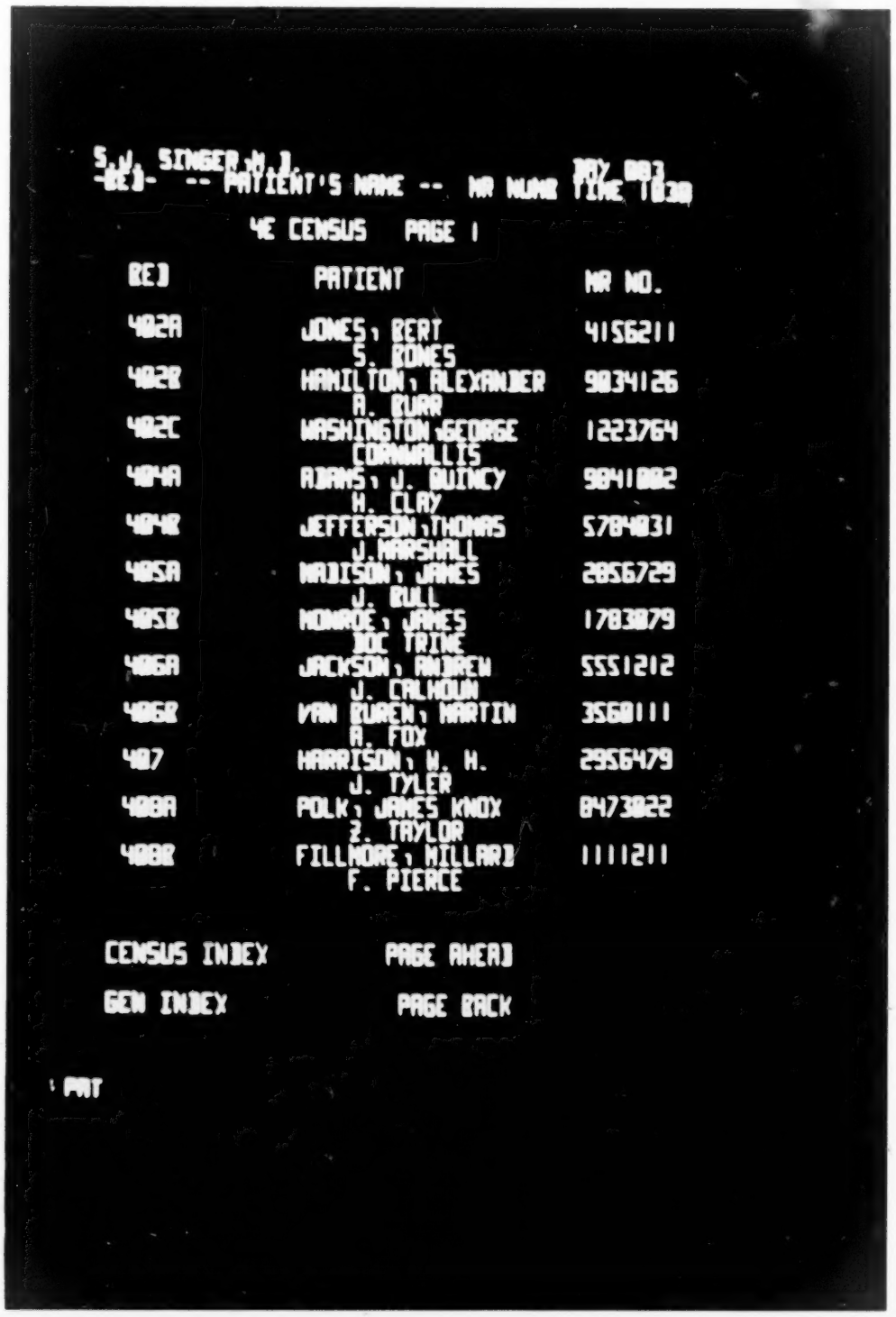

Figure 4. Patient census display

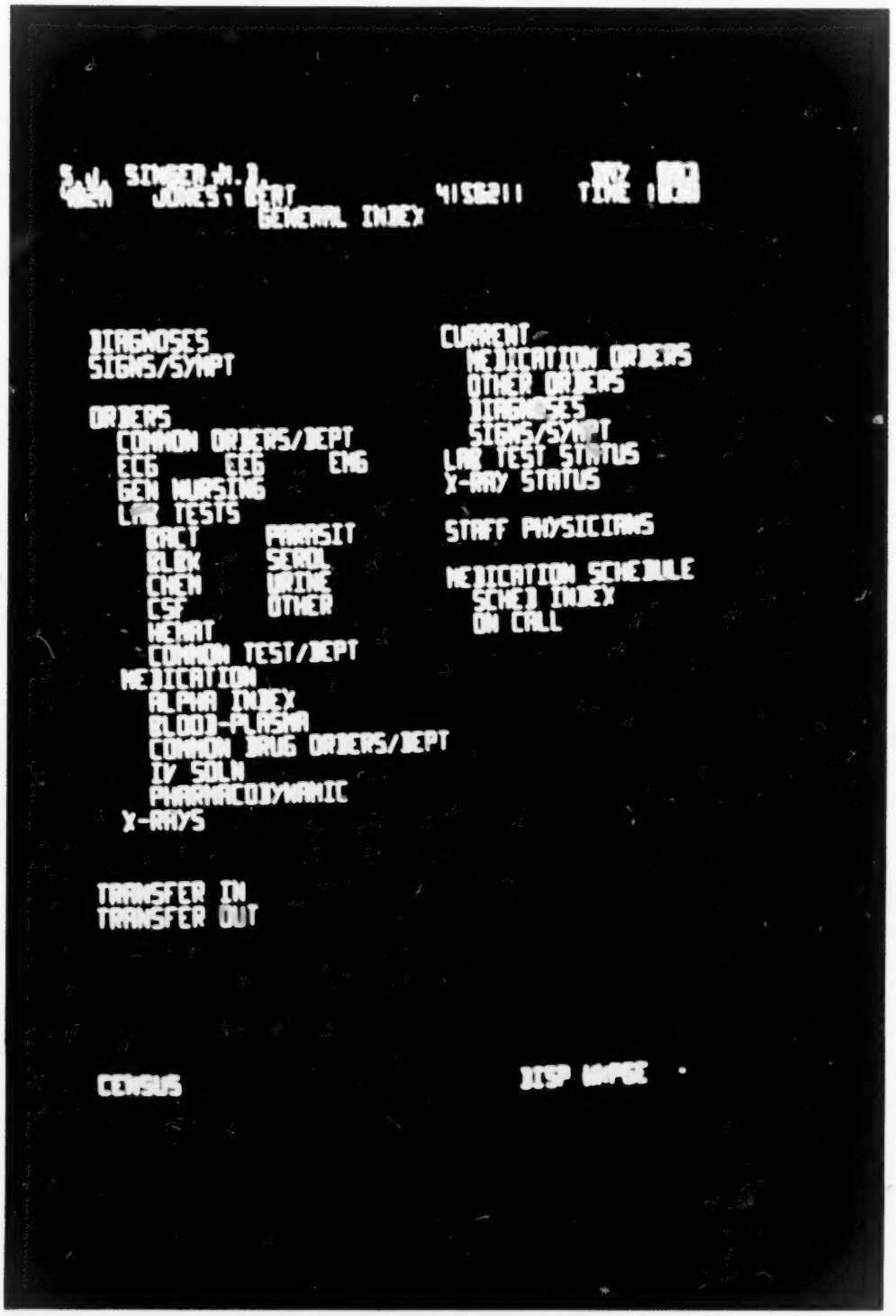

Figure 5. General index display

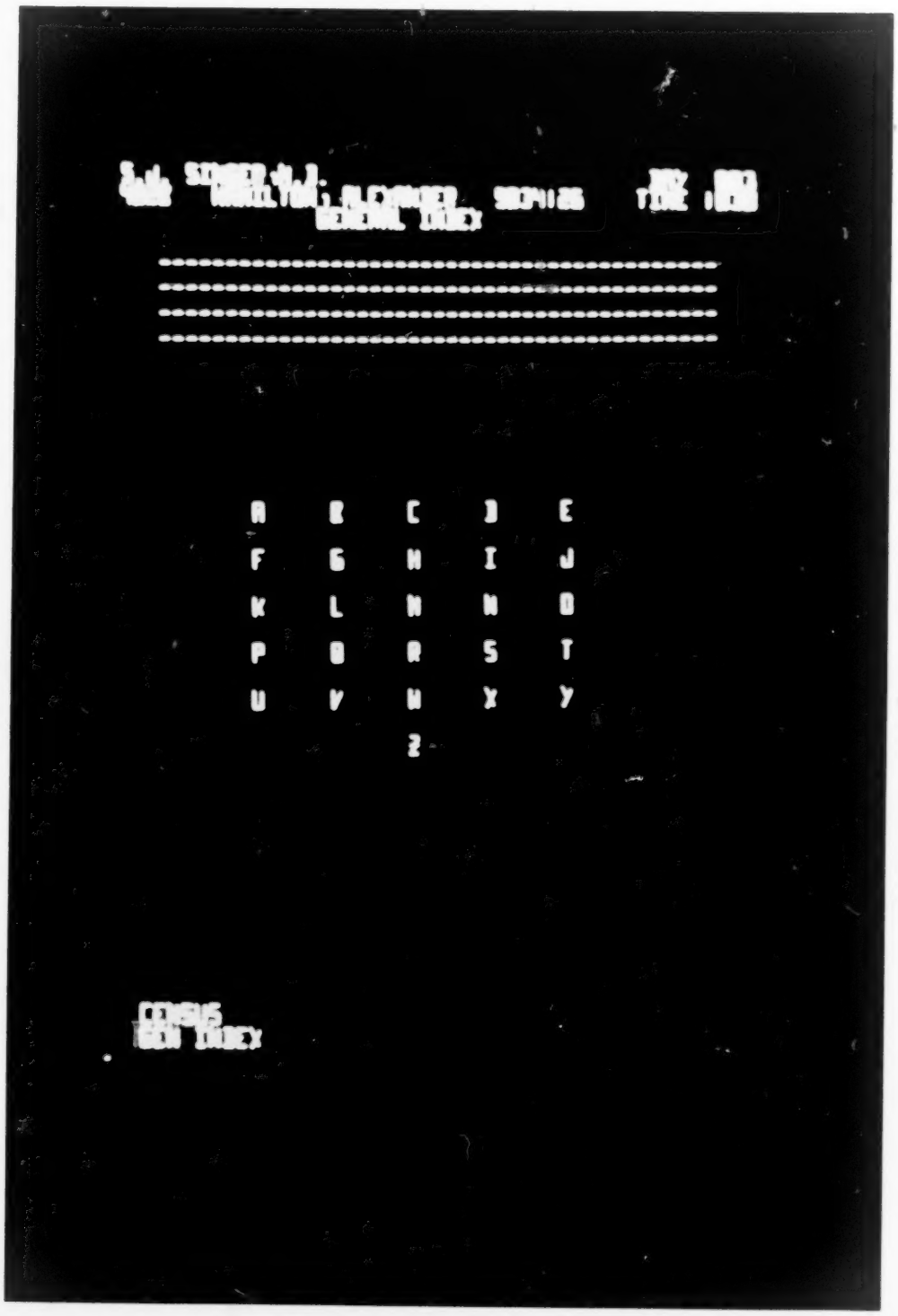

Figure 6. Alphabetic drug index display.

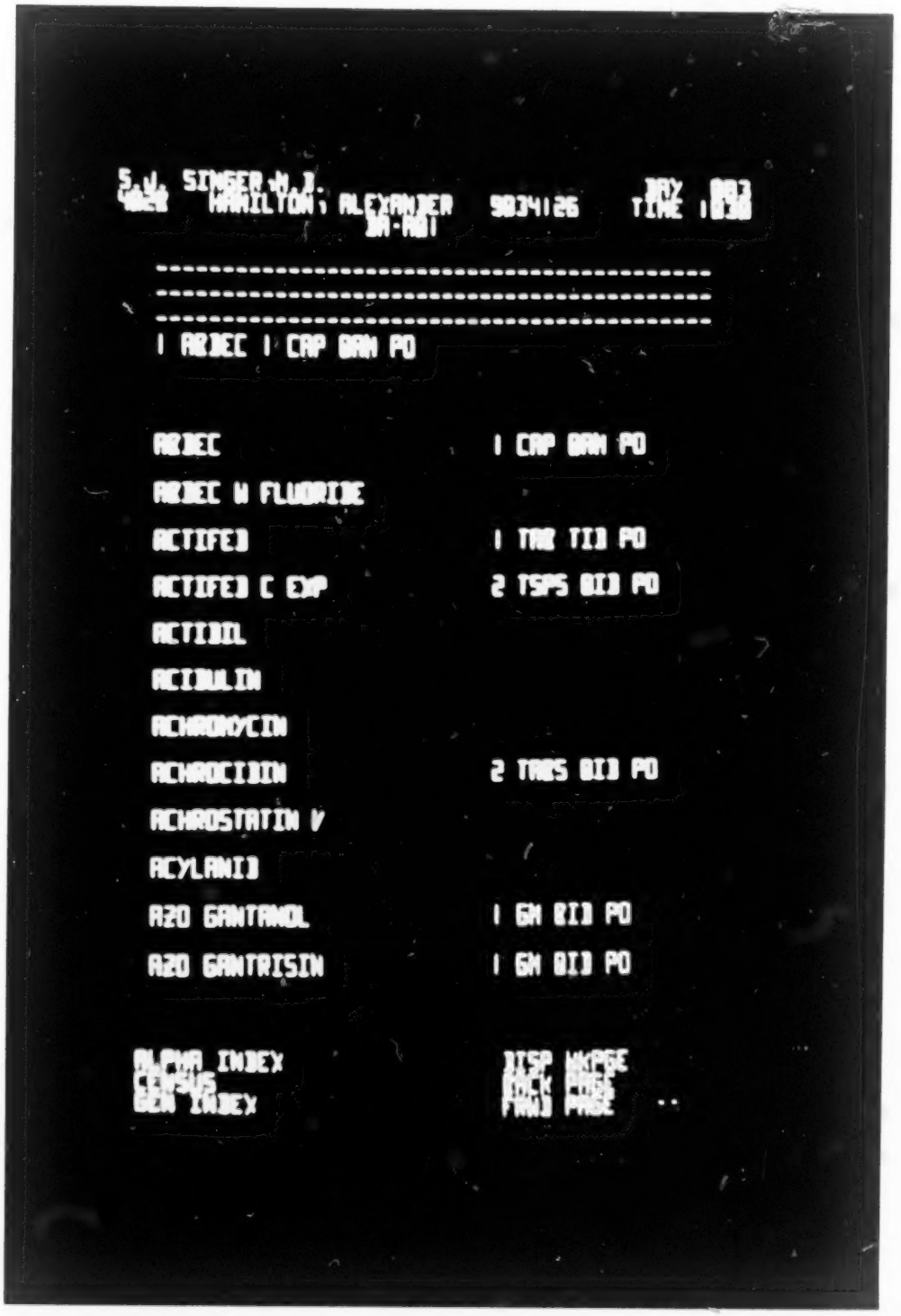

Figure 7. Alphabetic list of drugs.

selecting the function, "Forward Page" at the bottom of the display will produce the next page in the alphabetic drug list.

The drug list is structured as follows: on the left are drug names and forms in alphabetic order; on the right are the most common orders for a given drug (if any). One can generate an entire order by light-penning the common order on the right, or simply by selecting the drug name. Selection of the drug name causes display of a drug "Sig Page", on which the drug name is displayed in the status area (Fig. 8). This allows for a large variety of selections for dosage, route, and frequency of administration. If an order exceeds one line, it is continued on the next line. Two sample orders are shown in the status area.

The ordering sequence is completed by selecting the function, "Display Work Page" (DISP WKPG). This results in display of all the orders generated at one time. The order sequence is ended by selecting one of two functions: "Print and Return to Census", or "Delete Orders and Return to Census". Orders are generally printed immediately, just as they appear on the display. They can then be initialed by the physician and later placed in the hospital chart.

DIAGNOSIS ENTRY

The input of a diagnosis illustrates another example of physician interaction with visual terminals. This sequence starts as does the drug ordering sequence. It differs when "Diagnoses" is selected from the general index. This results in a display of diagnoses categorized into general groups. Selection of "Cardiovascular" causes a display of various groups of cardiovascular diagnoses to appear. This is another example of multilevel indexing. It allows faster selection of one of several diagnoses pages.

Several techniques improve readability of the display. If the first part of a compound diagnosis is the same for several diagnoses as in Atrial Fibrillation, it is omitted from the following ones. A large number of modifiers indicating severity, anatomic location, certainty, and chronicity are available for qualifying diagnoses. By convention, the diagnostic sequence is ended by an indication of chronicity (O = old, N= new, O + N = exacerbation of existing condition).

The diagnosis input sequence ends, as does the drug-ordering sequence, by displaying the work page and printing the diagnoses.

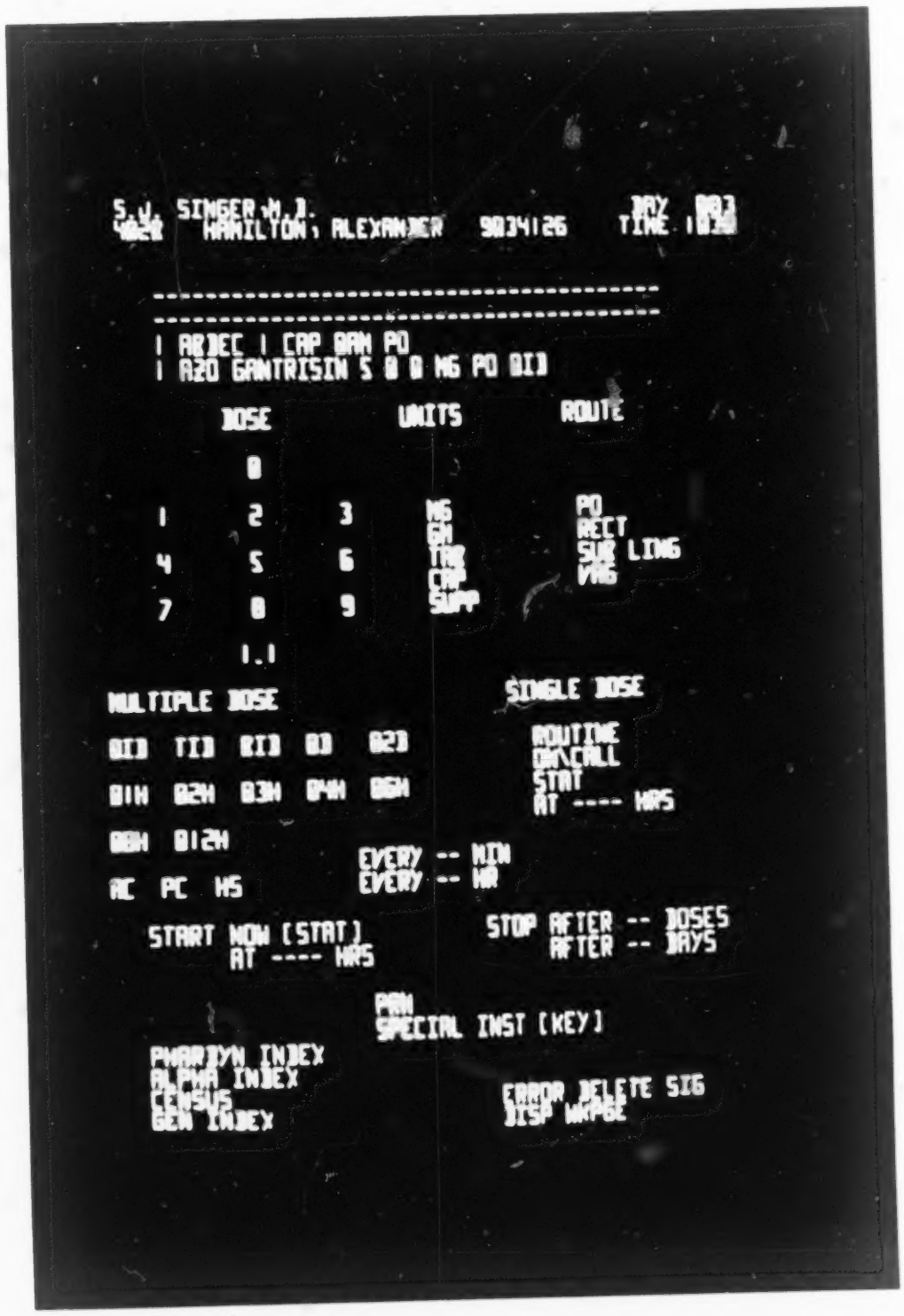

Figure 8. Drug order display for constructing complex drug orders.

DISCUSSION AND CONCLUSIONS

Although the system has not yet been installed in the hospital, it has been operated by a number of physicians, many of whom are unfamiliar with computers. Certain tentative conclusions are possible at present.

The over-all strategy is acceptable. Most persons can learn to "write" orders with only a few minutes' instruction and a little experimentation. Summary displays, which have not been discussed, are attractive to users since timely information, such as current active orders and the status of outstanding laboratory requisitions, is not otherwise easily available in the hospital.

Errors are frequent at first, but diminish with time. The most common error is an incorrect light-pen selection, which is noted immediately. Several techniques for error correction have been provided. Many displays have an "Error" function at the bottom. Light-penning "Error" once causes deletion of the most recent entry; light-penning it again causes deletion of the whole line. An entire entry may be deleted by displaying the work page and light-penning the entry.

Entries are presently checked for internal consistency. An error message is displayed and blinked in the status area to call the error to the user's attention. For example, the system will not allow only a modifier such as "right" to be entered as a diagnosis. Error checks for many entires are planned, for example, the dosage of drugs, the compatibility of drugs with each other, and of drugs with specific diagnoses. The primary limitation upon this type of checking is the processing time required and storage space for programs. It is the potential availability of this type of error checking that makes a hospital information system so attractive.

Efficient utilization of visual terminals requires structuring of data. Many currently used hospital forms are highly structured, such as an admission form; but others, such as a progress note form, are essentially blank pages. While a computer can handle unstructured English text, the process is slow and error-prone; and the visual terminal offers little advantage over a simple typewriter terminal. The diagnosis input sequence represents a first step toward structuring doctors' progress notes.

Since it is not possible to anticipate every entry and to prestructure each visual display, most sequences allow for selection of a function such as "Other," which permits typing of free text into the status area of the display. To aid in improving displays, the system stores all typed-in entries for later summarization and review. Typed-in entries that are found to be frequently used will later be added to the display formats.

Present visual displays, especially character-generating units, are limited in character, form, color, etc. A well-designed paper form may allow for the entry of as much information as four or five visual displays of similar size.

One of the most critical factors affecting acceptance of visual display units in a hospital system is the "response time"—the time required to change displays. Response time must be at least so short that the user cannot make a mistake such as light-penning another entry before the computer has finished processing a previous entry; in practice, between one-half and one second. A longer response time may be acceptable for a new utility service such as preparation of summaries.

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COMPUTERS AND DOCTORS;

USE AND CONSEQUENCES

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INTRODUCTION

More and more, interactive computer programs are written for use by people other than the writer and sometimes these people have neither responsibility for nor vested interest in the use of the programs. The clinician is such a person. There are a number of reasons why others might want the practicing doctor to interact with a computer–these range from the profit motive (with the desire to to sell computers) to the credit motive (with the desire to publish papers on man-machine interface)–but reasons why the doctor himself would want to interact with the computer are not readily apparent. Probably no one has less vested interest in using computers than practicing physicians. Prophecy– sometimes a substitute for accomplishment in computer medicine–has threatened them with loss to the machine of their decision making role and neither they nor their patients have benefited much from computers as yet.

Under what circumstances then will a physician interact with computers or computer terminals? B. F. Skinner[1] has provided the model–operant conditioning–and Ramond and Slack[2] have suggested its application to the use

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of computers by people not paid to use them. According to this model, behavior is determined by its consequences. Behavior can be shaped into relevant responses when the results of this behavior are reinforcing. The rate of occurrence over time of these responses is controlled by the scheduling of the reinforcing stimuli. In other words, if physicians are to interact with computers the consequences of this behavior must be reinforcing. Money and research interests–the usual reinforcing stimuli for operating computers–don't apply to the clinician. He is paid to care for sick people and is too busy to maintain a sustained interest in other people's research.

COMPUTER-BASED PHYSICAL EXAMINATION SYSTEM

Our experience with physician–computer interaction began with a program designed to interview physicians regarding their findings on physical examination.[3,4] Our primary research interest was to see if the technique could provide physical examination data of good quality in computer processable form–available for retrieval for use in patient care and research analysis. By collecting the data directly from the physician we hoped to eliminate the problems that beset traditionally recorded physical examinations–incompleteness, illegibility and lack of standardization–and to bypass intermediary data manipulation between physician and computer.

In designing this program we reasoned that the least satisfying aspect of performing a physical examination was the necessity to record it; and that the reinforcing stimulus to the doctor– presented as a consequence of his use of the computer–would be the automatically generated, legibly typed summary of his findings.

Physicians sat at the computer console (*L*aboratory *IN*strument *C*omputer),[5] read the frames displayed on the cathode-ray screen, and responded by pressing appropriate keys on the keyboard. The basis of the computer interview was the logic of the traditional physical examination. The computer questioned the physician about routine physical findings; and branched, when his response indicated an abnormal finding, to a series of qualifying questions designed to elicit details about the abnormality. A response indicating no abnormality resulted in the skipping of qualifying questions and the presentation of another general question. A response indicating that part of the examination was not performed resulted in the skipping of further questions about the omitted portion. Thus the presentation of questions was a function of the examiner's response.

The program was initially designed for use by gynecologists who had examined patients with uterine cancer, and that portion dealing with the pelvic examination was more detailed than the remainder of the physical examination. At the end of each major section (e.g., neck, lungs) the examiner could enter any relevant findings not included in the program; at the end of the interview he was asked to make general criticisms of the program. With the initial experiment the results of 50 physical examinations were obtained by computer interview–40 from gynecology residents and 10 from staff physicians. Completion times ranged between 8 and 34 minutes with an average of 17 minutes. A problem of computer accessibility existed (the machine used was about 130 yards from the gynecology nursing station) and residents were asked to discount this when evaluating the system.

When asked on self-administered forms their judgment of the program, all residents agreed that the computer system was generally preferable to the traditional approach. All preferred the computer for "legibility and standardization of the printed summary" and for its potential for "storage of findings for use in patient care and research." Two residents indicated that the computer was saving them time. The third indicated that in practice it took him less time to record his findings by hand than to enter them in the computer. All agreed that it was more time-consuming to write by hand a summary as detailed as the computer's, than to enter the findings directly in the computer. One examiner preferred the mechanics of handwriting to those of button pushing (this physician had no experience with a typewriter and had some difficulty with the open-ended questions requiring full keyboard typing), but in spite of this he found the computer system to be a time-saver. One resident preferred the detail of his own handwritten gynecology findings, but found the computer-printed summary of the rest of the examination preferable.

We concluded that the experiment was successful; that physicians would in fact press keys on a computer keyboard in response to questions about their physical findings, and that the computer's summary was in fact a reinforcing stimulus. As it turned out, however, we had oversimplified the situation when interpreting our results.

Since our initial experiment, 150 additional physical examinations have been collected by computer.* The enthusiasm of residents using the program

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*This was part of a uterine cancer study sponsored by the Regional Medical Program, under the direction of Dr. Ben Peckham.

has waned. The computer used for the uterine cancer program is still remote from the ward and this lack of proximity remains an important problem for the residents. However, distance alone cannot explain why the program would probably suffer disuse if it were not now departmental policy that the physical findings of all patients with uterine cancer be given to the computer. Somehow, the consequences of using the computer ceased to be reinforcing.

This is our explanation. The physical examination program included two phases of doctor-machine interface. The first was an orientation phase, in which the doctors were learning to use the program and being reinforced for doing so. During this phase the computer was fun to use and the explanatory frames written to guide the physician through unfamiliar paths were helpful. The use of short questions (usually one per frame) seemed to avert confusion. The unexpected but reasonable presentation of certain frames was interesting, touches of humor in the program were appreciated. The manner in which the computer questioned the examiner served as a reminder of the ways in which abnormal physical findings present themselves, and of which findings should be generally checked for on routine physical examination. The lengthy printed summary, automatically generated, was impressive. It demonstrated, with its detail and inclusion of pertinent negatives, that the computer was actually saving and dealing appropriately with the information it had obtained. We plan to retain these reinforcing features in an orientation program which will be designed specifically for inexperienced physicians. With the entry of data from the first 50 patients the orientation phase was also an experimental phase—this was the first time physicians had been asked to interface with a computer for the purpose of entering physical examination findings and the program was being revised in accordance with suggestions made by the participating physicians—and the participants were probably working on behalf of the success of the experiment (Hawthorne effect).

The second phase (routine use phase) began with the termination of the experiment and the continuation of the program primarily for the purpose of obtaining uterine cancer data for research analysis. With this phase, factors which were reinforcing during the orientation phase ceased to be so. The novelty wore off, explanatory frames became an annoyance, the inefficiency of the frame formats and familiarity with the branching logic bred impatience, and the Hawthorne effect (which will disappear eventually even from the orientation phase) disappeared. The computer-generated summary—now criticized for being too long and difficult to read—was inadequate on its own as a reinforcing stimulus. Therefore, we need a second program—one designed for use by the physician who is oriented to the computer and who will be

adequately reinforced only by a program that permits the entry of findings in a manner consistently easier than the mechanics of handwriting, and that generates a well-organized summary without unneeded verbiage.

Two other systems for the entry of physical findings by physicians into computers have subsequently been reported.[6,7] The initial reaction of physicians who have interacted with these computers has been favorable. However, it is too soon to tell what the long-range consequences will be for the use of these programs.

COMPUTER-BASED MEDICAL HISTORY SYSTEM

Interactive computer programs designed for limited use by one person contain no routine use phase. Our computer-based medical histories and intern applicant interviews are examples of such programs. Prior to the physical examination study we had conducted an experiment in which patients were asked to interact with the computer, which had been programmed to obtained their medical histories.[8,9] Patients were found to react positively to the experience and these results have been corroborated by others.[10] The attitudes of patients toward the computer as a medical device are different from those of physicians because of the differences in their roles. Patients know that their responses will be used to help them with their medical problems, and this knowledge is reinforcing; but novelty of the technic and Hawthorne effect were probably operational in them as well as in physicians. The important difference is that patients were interacting with the computer only once or twice (orientation phase), while the doctors were using the machine daily. Patients' enthusiasm, we are sure, would wane with repeated interviews unless new computer-based histories were developed for the experienced patient.*

COMPUTER-BASED INTERN INTERVIEW

In another experiment, 30 senior medical students applying for internships at the University of Wisconsin Hospitals were interviewed by the computer regarding their backgrounds, interests and plans for the future.[11] The goals

*This waning enthusiasm would be analogous to the irritation expressed by a patient who has been examined by a medical student, intern, resident, and staff physician and is then asked to "tell his story" again to a series of medical students practicing history-taking.

here were to develop a system that would improve the applicant's visit (organizing it in accordance with his interests and optimizing his contacts with people in the medical school), and to save staff time. The computer interview eliminated the necessity of filling in application forms; upon completion of the interview it was hoped that this would prove to be a reinforcing stimulus. In addition to obtaining information from the applicant, the computer offered to provide him with information about the internship program (disadvantages and advantages) as well as the university and the community where he would be living and working. The interview was well received. Of 29 applicants asked about the interview, 28 found it interesting and liked responding to the questions and 26 preferred the computer interview to filling out written forms. As with the patients, however, the applicants were interviewed only once by computer.

INTERACTIVE PROGRAMS THAT PROVIDE INFORMATION

We have been discussing interactive programs whose primary purpose is to obtain information from the user. In another type of interactive program, a primary purpose is to provide the user with information. Information of immediate use should be a good reinforcing stimulus, and interactive programs that provide useful information to physicians (as well as collecting information from them) are likely to be used repeatedly. Lindberg,[12] Bleich,[13] and Warner[14] have found this to be so with programs providing information about diagnostic possibilities, management of fluid and electrolyte problems, and cardiac status. Sweeney[15] has developed a file system (GYPSY) with interactive retrieval capabilities permitting the user to ask a wide variety of independent or interrelated questions. In preliminary trials, physician users have found the information provided to be reinforcing.

CONCLUSION

When considering the interaction between physicians and computers it is helpful to analyze the reinforcing quality of the consequences of the physicians' behavior. Our computer-based physical examination system showed that factors which were reinforcing while the physician was orienting to the computer became nonreinforcing when he was using the program routinely. A preliminary program with detailed explanatory frames would be useful with

physicians who are learning to operate the machine and who are still being reinforced by the novelty of the experience. Once the physician is oriented, the operation of the computer must be easier than the mechanics of handwriting and the summary must be better than his own.

Of course, the only way to really know if the consequences of physican-computer interaction are continually reinforcing will be to see what the experienced physician does when he has a computer (or terminal) available in his examining room but is under no obligation to use it.

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MASS RANDOM STORAGE DEVICES AND THEIR APPLICATION TO A MEDICAL INFORMATION SYSTEM (MIS)

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INTRODUCTION

In designing a system for processing large volumes of data, it is important to select a mass random storage device whose capacity and access times are adequate for the needs of the system. Since Craver's[1] extensive review of mass memories available in 1966, there have been numerous articles on specific developments in memory technology.[2-9] The problem of selecting a mass memory has assumed major proportions for the medical information system (MIS) developed by Kaiser-Permanente, because the system must store data on almost one million persons, each of whom must have a computer medical record accessible at any time, eventually from any of the twelve Kaiser medical facilities. To begin to meet this situation, two IBM 2321 Data Cells were installed two years ago for the storage of patient computer medical records.

FUNCTIONAL REQUIREMENTS

Specifications for a mass random storage device fall into six major categories: total on-line storage capacity (for single and multiple units), access time (average and worst case), data transfer rate, reliability, programmability, and cost.

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Total On-line Storage Capacity. The contents of a patient computer medical record (PCMR) have been described elsewhere.[10] Since each PCMR, which contains identification, administrative and medical data, may consist of hundreds or thousands of characters (bytes), to store all medical records of a million persons requires a storage device with a multi-billion bit capacity. The spectrum of computer storage devices available, with their relative capacities and access times, is presented in Table 1. In general, the greater the storage

Table 1.–Characteristics of Computer Memories

Storage Device	Maximum Bit Capacity	Typical Access Time
Core storage	6×10^6	1 μsec
Extended core storage	8×10^6	4 μsec
Magnetic tape	50×10^6	1 min
Magnetic drum	10^9	20 msec
Magnetic disk	10^9	75 msec
Mass random storage	10^{12}	1 sec

capacity, the slower the access time. Clearly, the functional requirements for storing a million records with direct access capability can be met only by a device in the last category, a mass random storage device. Furthermore, the volume of medical data is steadily increasing. Even if the total population were stabilized at a fixed number, the volume of medical data would continue to grow linearly, assuming that patients continue to receive medical services at a constant rate. If the population is allowed to grow at a constant annual rate, and if the average increase in size of a PCMR per year is constant, it can be shown (see appendix) that the total volume of PCMR data will increase quadratically with time, according to the formula:

$$T_n = \frac{n^2PK}{2} + nNK + T_o$$

where

T_o = total number of bytes in all PCMR's in year 0
T_n = total number of bytes in all PCMR's in year n
n = number of years
N = number of persons in population in year 0
P = annual growth rate of population
K = average number of bytes added to each PCMR per year

Figure 1 presents a comparison between total on-line storage available and actual volume of PCMR data stored in Data Cells up to the present time.

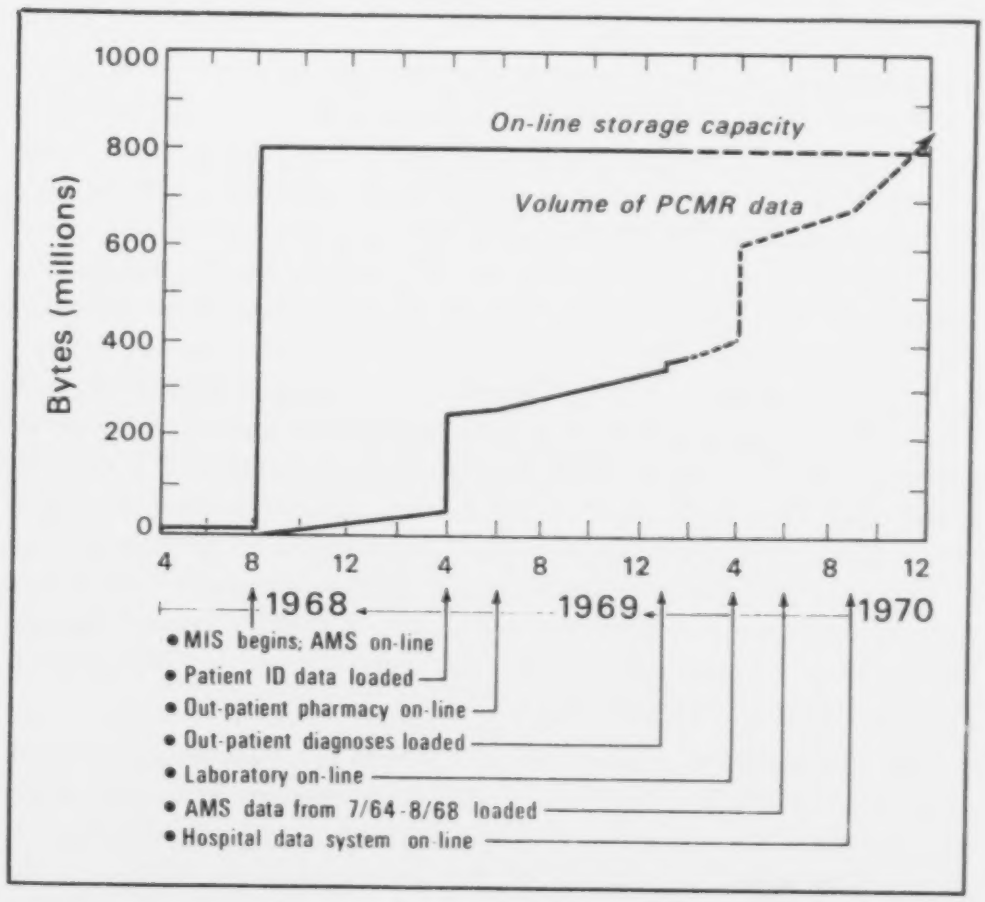

Fig. 1. On-line storage capacity and volume of patient computer medical record (PCMR) for Medical Information System at Kaiser-Permanente. Dashed extensions of curves represent current projections of storage capacity and volume of PCMR data. Events accounting for changes in volume or rate of data acquisition are indicated along time axis.

Abrupt increases in the volume of PCMR data were due to the initial loading of large volumes of patient identification and administrative data, and outpatient diagnoses. Currently, a single PCMR may contain identification and administrative data (120 bytes), medical data from Multiphasic Clinics in San Francisco and Oakland (1200 bytes per visit), San Francisco clinic pharmacy data (100 bytes per prescription), and diagnoses from San Francisco outpatient clinics (30 bytes per visit). These data form only a small fraction of the total volume of medical information that will be received when the system

goes into full operation. The bulk of the data will come from medical services to hospital inpatients, including drug orders, drug administrations, and laboratory test results. There is little doubt that within one to two years, additional storage will be needed.

Access Time. It must be possible to access randomly any PCMR in storage in order to retrieve a record within an acceptable time. The selection of this retrieval time was a result of the basic philosophy: that use of the MIS must not impede the delivery of medical services in any way. Two considerations in determining maximum PCMR access time were: (1) the expected peak load of PCMR retrievals in a given period and (2) the problem of man-machine interaction. Surveys of all Kaiser-Permanente outpatient clinics in the Bay Area have demonstrated total work loads of 14,000 patients per day and peak loads of 2000 patients per hour. Pharmacy operations show similar work loads for the filling of prescriptions. Since these medical services will have to operate on-line in real time together with hospital inpatient functions, it is clear that PCMR access times in excess of 1 second would result in frequent queuing of retrieval requests and consequent retardation of operation of these services. Furthermore, utilization studies of visual display terminals[11] at nursing stations have shown that physicians and nurses will tolerate terminal response delays only of the order of 1 second. Thus, an access time of 1 second or less was specified for the storage device.

Data Transfer Rate. Once a record is located in a mass storage device, it must be transmitted to central core storage for further processing. All existing mass memories have data transfer rates above 50,000 bytes per second. At present these rates are adequate for the Kaiser-Permanente MIS, since the longest PCMR now stored in a Data Cell contains only 7000 bytes. In the future, however, as PCMR's enlarge, this specification may well become the limiting factor in selecting a mass memory.

Reliability. An MIS, to operate effectively, must perform with a reliability near 100 percent.[11] It was arbitrarily decided that all system components should have a reliability of at least 98 percent and it was hoped that the chosen mass memory would be no exception. However, as will be described later, our experience with the Data Cell has proved otherwise.

Programmability. A mass random storage device should be easily programmed; i.e., its front end or controller should be compatible with the current operating system. A device with hardware incompatibilities may require extensive interface programming to overcome the differences. This was not a problem with the Data Cell, since it is an IBM storage device and is directly

compatible with the IBM 360 Operating System used by Kaiser-Permanente.

Cost. The cost of mass memories varies from $60,000 for a billion bit magnetic card memory to $1,000,000 for a trillion bit optical memory (see Table 2). Cost per bit varies inversely with size from .0060 cents to .0001 cents, respectively.

DATA CELL OPERATION

Two IBM Data Cells are used by the MIS for on-line PCMR storage. The system is so designed that the first time a patient's record is accessed each day, his PCMR is retrieved from the Data Cell in its entirety and transmitted to an intermediate device, an IBM 2314 disk storage unit. This is done because if a PCMR is accessed once during a day for any reason, there is a high probability that it will be accessed again within a short period. Since the average access time for a record on disk is only 75 milliseconds compared to 400 milliseconds for a Data Cell, placing a PCMR on disk greatly decreases access times for subsequent data retrievals. This procedure also serves to minimize use of the Data Cells by avoiding additional Data Cell accesses for the same PCMR on the same day. At the end of the day all PCMR's on disk have been updated and are transmitted back to the Data Cell. The updated PCMR's are stored at the end of the active file in the Data Cells, while the storage areas formerly occupied by the old PCMR's, which are no longer valid, can be reused by the system after appropriate cleanup procedures.

There have been approximately 3 million Data Cell accesses since they began on-line operation in August, 1968. We estimate that about one half of these PCMR retrievals were initiated by transactions in the pharmacy and multiphasic clinics and by the initial loading of PCMR data, while the remainder were due to the operation of data retrieval programs and internal systems programs. At present an average of 3600 retrievals of PCMR's are made from the two Data Cells per day.

In view of the large number of PCMR retrievals, the reliability of the Data Cells is of major importance for efficient system operation. When a Data Cell or its controller is disabled, no PCMR is accessible unless it had been transmitted to disk before breakdown. Medical information for entry into a PCMR stored in a disabled Data Cell must be saved in temporary storage on disk, tape, or off-line, in the form of punched data cards or written documents, until the Data Cell can be repaired. Figure 2 shows conservative estimates of the hours of down time per month for the Data Cells since installation, including machine

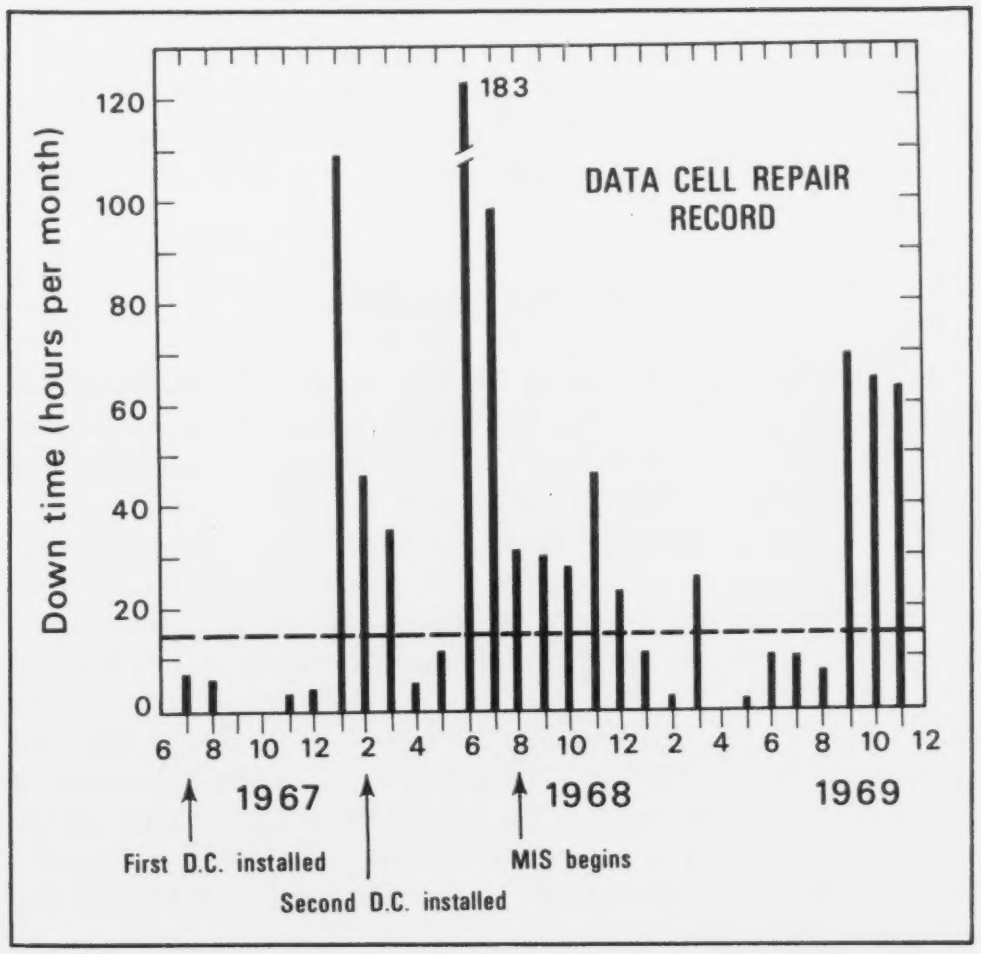

Fig. 2. Data Cell repair record showing hours of down time per month. Dashed line at 14 hours represents 98% operational reliability based on a 24 hour work day for on-line Data Cell operation. Down time includes machine outage affecting system operation both for preventive maintenance and failures for which IBM engineers were called.

outage for preventive maintenance, and for mechanical failure for which IBM engineers were called. The values do not include data checks and failures resolved by our own personnel. The 98 percent level of reliability is represented by the dashed line. Of all computer system hardware, the Data Cells have had the poorest operating record. This result is not too surprising because the Data Cells contain a greater number of moving parts than any other system component. Based on their past performance, we are concerned that the Data Cells may be inadequate for the requirements of a fully operative MIS. We are considering two possible alternatives: (1) to find a more reliable mass random storage device to replace the Data Cells, or (2) to install a third back-up Data Cell to be used when one of the others fails.

ALTERNATIVE MASS RANDOM STORAGE DEVICES

Principles of Operation. Many types of mass memories are currently available. Table 2 summarizes storage capacity, access time, data transfer rate, total cost (excluding controller), and cost per bit of several devices. Although storage media and techniques differ, certain basic features are common to all mass storage devices. A complete storage unit consists of an array of storage elements arranged in modular fashion. Each element is an individual storage medium, such as a magnetic strip or photosensitive card, capable of storing binary data at discrete points by means of a change in its physical state (e.g., by a change in magnetization, reflectance, or light transmission). Data points are closely spaced, having bit densities of up to 25 million bits per square inch. To transmit data to or from a storage element, the element must be extracted from its module and positioned under one or more read/write heads, usually on a rotating drum. After appropriate fine positioning movements of the head, the desired storage address is located and data transmission proceeds. The process of moving the selected storage element from its module to a position under the read/write head both limits the access time of most mass memories to the order of seconds or tenths of seconds and has the highest probability of failure of any computer operation. In contrast, magnetic disk memories have the fastest access time and highest reliability, because each disk rotates continuously in a fixed plane between individual moveable read/write heads, and no additional storage element positioning is necessary. Disk memories are also among the most expensive of the mass random storage devices in terms of cost per bit.

Specific Devices. The various storage techniques in current use can be divided into two basic categories: magnetic and nonmagnetic. Until recently, nearly all mass memories used magnetic storage elements in the form of cards, strips, drums, or disks. Since magnetization is reversible, data bits can be erased from the medium and the storage element is reusable. Examples of devices using this principle include the IBM Data Cell, RCA Race, NCR Cram, and all disk and drum mass memories.

Nonmagnetic mass memories generally use optical techniques for storing data. Optical storage media currently available are noneraseable and are, therefore, most useful for archival types of application. Basic differences between optical and magnetic storage techniques are illustrated in Figure 3. The largest nonmagnetic mass random storage device, and the first trillion bit memory commercially available, was the IBM 1360 Photo-Digital Storage

Table 2.—Characteristics of Mass Storage Devices Currently Available

Storage Devices	Storage Capacity (bits)	Maximum Access Time (sec)	Data Transfer Rate (megabits/sec)	Cost Per Unit	Cost Per Bit (cents)
NCR Cram	10^9	.2	.5	$60,000	.006
IBM 2321 Data Cell	3.2×10^9	.6	.4	$128,000	.004
RCA Race	4.5×10^9	.75	.6	$130,000	.003
CDC 821 Data File	5×10^9	.135	2.5	$265,000	.0053
IBM 1360 Photo-Digital	10^{12}	180	1	$1,000,000	.0001
PI Unicon	10^{12}	8	4	$1,000,000	.0001

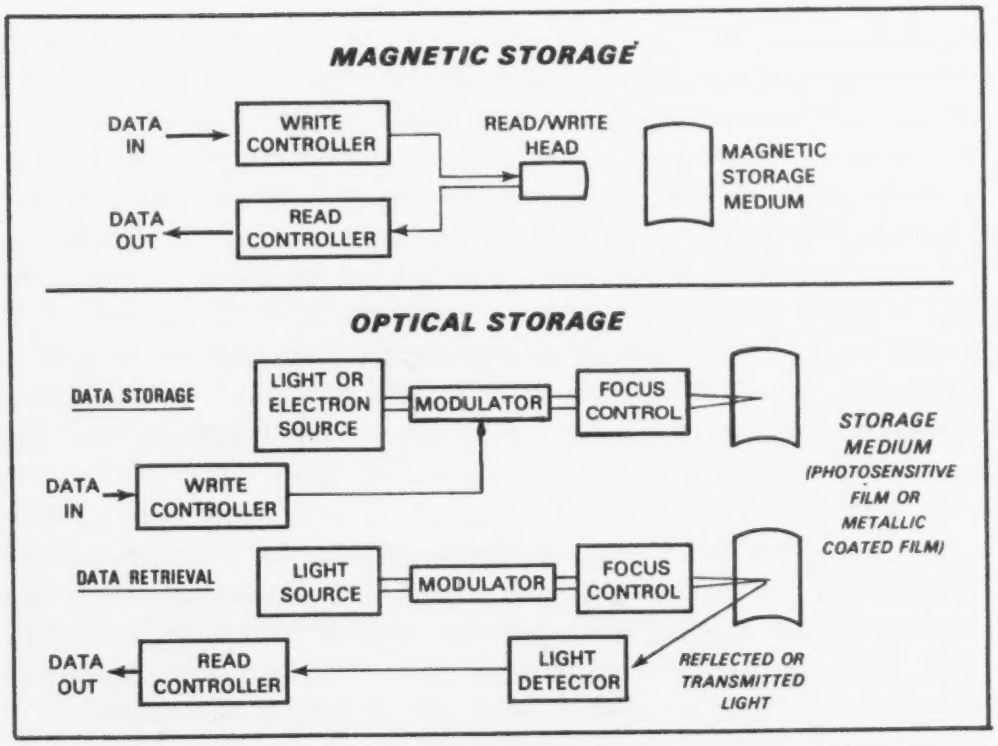

Fig. 3. Block diagram of mass random storage device showing basic magnetic and optical storage techniques. Although data storage and data retrieval are represented as independent operations in the optical storage illustration, many components of each subsystem may be common to both.

System.[3] Binary digits are permanently written with an electron beam on photosensitive cards, which then undergo a chemical developing process lasting about 3 minutes. After development, data appear as arrays of transparent or opaque spots on the film and are read out with a flying spot scanner. Average access time after development is about 3 seconds.

The Precision Instrument Unicon is a new laser-driven optical mass memory with a trillion bit capacity. An intense laser beam vaporizes minute holes in the metallic surface of a coated plastic strip. Using a beam of lower intensity, data are read out by detecting variations in reflectance between vaporized and nonvaporized points. Average access time is about 4 seconds.

MASS RANDOM STORAGE DEVICES IN THE FUTURE

None of the mass memories currently available meet all our requirements for storage capacity, access time, cost, and reliability. In devices where storage

capacity is adequate, access time is too slow; in devices where access time is satisfactory, storage capacity is too small; and to use a large number of fast access, small capacity storage devices would be prohibitively expensive. Fortunately, there are good prospects for the development of a storage device that will satisfy all requirements, as the state-of-the-art for mass memories advances. With the use of optical techniques for data storage, bit densities on the order of billions of bits per square inch are theoretically possible, the density being limited only by the wavelength of light. Recently, IBM announced the development of an experimental laser read-only memory in which data are stored on a photographic plate in the form of a hologram. Complementing this development, RCA has combined magnetic and laser techniques to produce an eraseable magnetic hologram for application with mass memories.[6] Also, Ovionics has reported the development of an eraseable optical storage medium. This material has the property that a laser beam of one intensity can alter the refractive index at the point of incidence, while a laser beam of another intensity can restore the refractive index to its initial value. RCA is also investigating cryoelectric memories using superconductive storage elements.[4] The physical basis for this type of memory is the transition of certain metals between superconductive and normal states as a result of the application of a magnetic field. Another technological development that may be applicable to mass memories of the future is the creation by Bell Laboratory engineers of magnetic "bubbles" in rare-earth crystals.[7] When the crystal is placed in a magnetic field and viewed with polarized light, the bubbles appear as round spots whose presence or absence in precisely defined locations can represent binary digits.

Commercial applications for most of these developments are several years away. Our needs for a suitable mass memory will become critical long before that time. In the interval it will be necessary to use available mass random storage devices that may not fully meet the functional requirements of an MIS.

SUMMARY

Six major criteria for selection of a mass random storage device are: storage capacity, access time, data transfer rate, reliability, programmability, and cost. Critical requirements for a mass memory for a Medical Information System with a population base of one million people are: a multi-billion bit storage capacity, direct random access time under 1 second, data transfer rate of at least 50,000 bytes per second, and at least 98% reliability.

The volume of storage occupied by patient computer medical records at Kaiser-Permanente is rapidly approaching the total storage capacity of two IBM Data Cells. Based on a two-year performance record, the Data Cell has proved to be only marginally reliable, and alternative storage devices are being considered as replacements.

Although numerous alternatives are currently available, no mass memory developed to date completely satisfies the requirements for a Medical Information System. As the state-of-the-art for mass memories advances, the prospects are good that future devices will meet the requirements, but commercial availability of such devices is several years away.

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APPENDIX

It is possible to compute the total volume of PCMR data in mass storage in any year, given certain initial conditions and constraints on the rates of population growth and of data acquisition.

Let t_0 represent the initial time at which the rate of PCMR data acquisition reaches a steady state; i.e., all specified medical functions under the Medical Information System supply PCMR data at a constant average rate of K bytes per PCMR per year. Assume that this rate remains constant over the period of interest and that no datum is ever removed from a PCMR. Let N equal the number of persons in the PCMR population at t_0. Assume that the population grows uniformly at a constant rate of P persons per year. Let T_0 equal the total number of bytes in all PCMR's of the N persons at t_0.

After n years the N persons in the original population will have accumulated an additional nNK bytes of PCMR data. Therefore, the total number of bytes of PCMR data for N persons after n years is $nNK + T_0$.

If the population grows uniformly at a constant rate of P persons per year, one year after t_0 this new group will have acquired PK/2 bytes of PCMR data. At the end of the second year that same group will have accumulated an additional PK bytes of data, but a new group of P persons added to the population in the second year will have acquired PK/2 bytes. Thus, each year new PCMR data from persons added to the population after t_0 accumulate in the following way:

End of Year	Number of Additional Bytes of PCMR Data
1	PK/2
2	PK + PK/2
3	PK + PK + PK/2 . . . .

After n years the total number of bytes of PCMR data accumulated by persons added to the population after t_0 is:

$$\frac{nPK}{2} + \frac{n(n-1)PK}{2} = \frac{n^2PK}{2}$$

Thus, the total number of bytes of PCMR data for the entire population after n years is given by:

$$T_n = \frac{n^2PK}{2} + nNK + T_o$$

This equation probably represents only a lower bound for the amount of on-line PCMR storage required, because of the linear constraints placed on the growths of population and PCMR size in the derivation. In reality the annual growth rate of the Kaiser Health Plan population is likely to accelerate over the years and the average size of a PCMR will aso expand at an increasing rate as additional medical tests and procedures are programmed into the Medical Information System.

PROTOTYPE FOR FUTURE COMPUTER MEDICAL RECORDS

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INTRODUCTION

Despite widespread interest in computer processing of data for medical information systems,[1-5] only subsets of systems, such as business information or laboratory data, have been implemented.[6-9] Often, several medical applications are under study or implemented in a single institution, all researchers using the same computer, yet the various datasets are incompatible as to encoding, definitions, and other aspects of design. Each user orients his program to the medical question he is trying to answer; such considerations as data compatibility become subordinate. The individual user has neither the resources to develop, nor the authority to enforce a standard file structure for all the data in a system.

Yet success of an MIS depends upon a standard file structure, supported by all the system programs within it. The file structure must be applicable to all forms of medical data. The system programs should be efficiently coded. Error recovery and backup routines should be maximally thorough. The system must provide for capture and storage of all essential medical information in a standard, organized, and structured way, to give all potential clinical and

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research oriented users access to the data. The available information should include data about the current and all previous patient visits.

If a machine-readable file containing such records, each directly accessible, were available together with supporting computer software, various medical applications could be modularly designed, programmed, and implemented. Each user would then have immediate access to all known medical information about each patient.

A PROTOTYPE COMPUTER MEDICAL RECORD

A file structure encompassing the above requirements is one facet of the Medical Function Control System (MFCS),[10,11] a large and complex set of interacting programs for receiving, storing, and retrieving medical data on patients of the Kaiser-Permanente health care system. MFCS is designed to control and coordinate general and fundamental routines including the handling of direct access storage devices, remote terminal input and output devices, and modular application routines.

At its center is the Patient Computer Medical Record (PCMR) direct-access facility. The PCMR is a continuing, integrated patient record designed to store all essential medical information for all office and hospital visits during the life of each patient. All PCMR's (currently more than 1,000,000) are individually retrievable by each member's medical record number, on a direct-access basis. Each PCMR within the computer direct-access storage facility is kept and moved together as a continuous string of data; it is never fractionated for overflow or any other reason.

BASIC STRUCTURE OF THE RECORD

The PCMR is a tree structure which progresses through *levels* of storage beginning at Level 0. A maximum of 12 levels (0-11) is allowed. Only 8 have been necessary for the various kinds of medical data stored up to this time.

The PCMR contains two kinds of data: *patient data,* received as input; and *program-generated data,* relating to the tree structure of the record. Program-generated data include branching, level, and record length information

which provide the PCMR processing programs with a trail through the tree. Each branching point is indicated by a program-implied or an explicit node identifier that includes the level (Fig. 1). A single node at level 0 indicates the

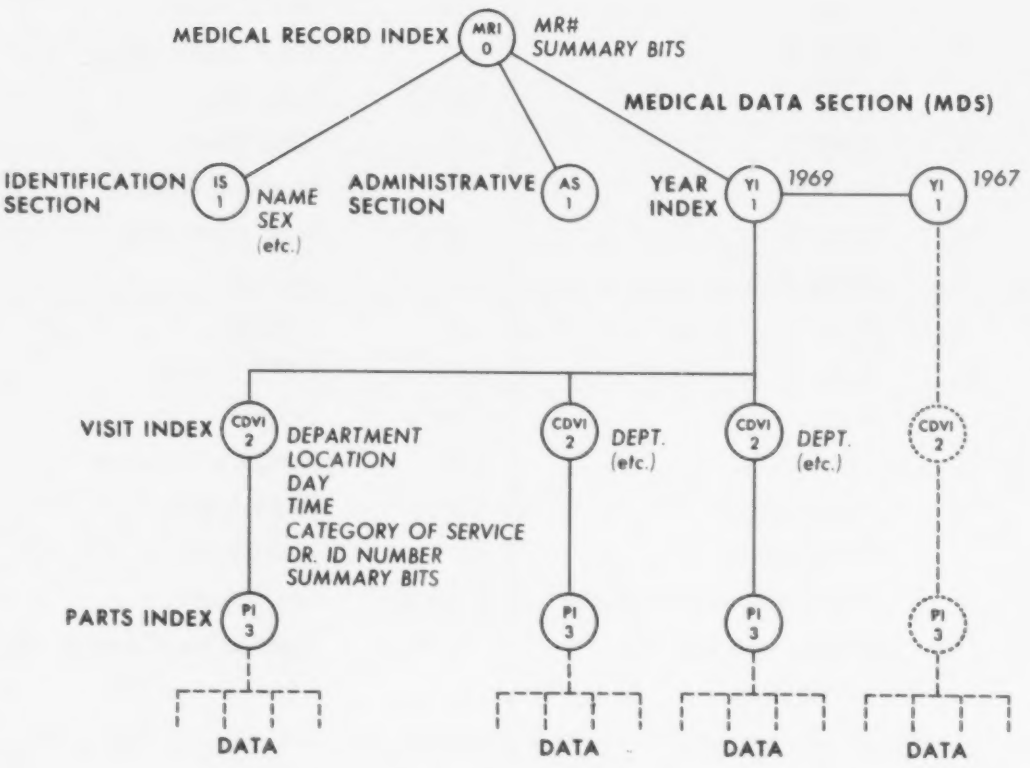


Figure 1. Schema of the first four levels of PCMR. Each node (branching point) is indicated by a circle labeled with the node level.

beginning of a PCMR. The single entry at this level, the Medical Record Index (MRI), contains the patient's medical record number, certain program-generated data, and a field of summary bits. Summary bits are indicators that signal the existence within the PCMR of selected classes of data. Some of the classes already defined are listed in Table 1. The summary bits are used to decrease retrieval time in responding to research requests across many records, by eliminating all PCMR's that do not contain the specified class of data.

Table 1.–Summary Bits

Bit No.*			
0	PART 0	18	Urinalysis
1	PART 1	19	Hematology
2	PART 2	20	PART 2 Other
3	PART 3	21	X-ray Contrast Study
4	PART 4	22	X-ray Chest
5	PART 5	23	X-ray Other
6	PART 6	24	Electrocardiography
7	PART 7	25	Surgical Pathology
8	PART 8	26	Autopsy
9	PART 9	27	Cytology
10	PART 10	28	PART 3 Other
11	PART 11	29	Drugs
12	Not assigned	30	Operative Procedure
13	Not assigned	31	PART 8 Other
14	Not assigned	32	Anthropometry
15	Reserved for Computer Use	33–50	Not assigned
16	Blood Chemistry	51–54	Reserved for Computer Use
17	Bacteriology		

*Bits 0 through 11, and 16 through 32 refer to information in the Medical Data Section only.

SECTIONS

Branching out from the single node at Level 0 (Fig. 1), the PCMR divides into three major sections, indexed at Level 1.

1. *Identification Section (IS),* a single node, currently contains up to 6 parts, each comprising a distinct type of data that identify the patient, entered when first learned or corrected:

Part 0: Data labeling the patient, e.g., name, social security number.

Part 1: Locations of the patient in time and space; e.g., birth year, month, place, street address, zip code, telephone number.

Part 2: Blood relationship identifiers; e.g., medical record numbers of parents, siblings, children; mother's maiden name.

Part 3: Nonblood relationship identifiers; e.g., medical record numbers of spouse, step-parent, adopted children.

Part 4: Certain unvarying physiological characteristics; e.g., sex, blood type.

Part 5: Certain categorical classifications; e.g., Automated Multiphasic Study Group codes, Medical Methods Research special study codes (for example, Japanese-American Health Research Program).

The manner of storing data in the IS is the same as that for Level 4 and beyond, in the Medical Data Section (see below).

2. *Administrative Section (AS),* also a single node, is at Level 1. Because the MFCS is operated primarily for medical care and research, the AS contains only those administrative data that are important in relation to research. For example, the type of health insurance coverage that the member holds in the Kaiser Foundation Health Plan might affect his exposure to medical care, thus biasing results in some research projects. It is therefore stored in *Part 0* of the AS. *Part 1* contains Health Plan-generated information not related to membership status, such as residence code.

Like IS data, AS data are stored in the same manner as for Level 4 and beyond in the MDS.

3. *Medical Data Section (MDS).* The basic strategy for grouping of medical data within the MDS was developed from the clinic visit concept. All data generated at and after the patient's appearance at one registration point are stored together. Specifically, data from: a location (Oakland, San Francisco, or other), a category of visit (office appointment, hospital visit, house call, or other), a department (internal medicine, pharmacy, laboratory, or other), a given date and a given physician are grouped with other input data having precisely the same collection point values. These groupings are called Computer Defined Visits (CDV).

The MDS may have multiple nodes at Level 1 (the point of entry into the MDS), called the Year Index (YI). A YI node exists for each year in which a patient has had at least one CDV (Fig. 1).

Level 2 of the PCMR comprises one visit index node for each CDV. Each Level 2 node locates the information, discussed above, that defines a specific CDV: location, visit category, department, date, physician. The time of the visit is also stored here, and a summary bit table for data that pertain to this visit. (The MRI summary bit table is the logical "OR" of all CDV summary bit tables in the record.)

MDS PARTS

MDS data for each CDV are subdivided into parts analogous to the parts of IS and AS. The parts index in Level 3 is an index pointing to where the information is stored, in Level 4 and below.

Part 0. Any information reported by any means (direct speech, telephone, correspondence, or other) from any source outside the Kaiser-Permanente medical entities. Examples include information from the patient, referring physicians, schools, agencies, lawyers; all parts of the classic medical history such as chief complaint, present illness, past history, family history, occupational history, etc.; results of tests reported from an outside laboratory.

Part 1. All observations currently made by any PMG physician on the patient as a whole, or on that anatomic system usually examined by the specific physician. Examples include results of physical examination, of tests (such as Romberg's or Weber's test) customarily performed on patients by physicians, observations of MD physiatrists (but not physical therapists), observations and results of office tests by neurologists, blood pressures measured by physicians, observations of anesthesiologists.

Part 2. Results of all tests of body fluids (urine, blood, cerebrospinal fluid, bone marrow, etc.) currently customarily performed in the laboratory, usually by technologists or automated equipment.

Part 3. Results of a specified list of studies performed by physicians or technologists on the body as a whole in order to test a specific organ or organ system. Examples are radiological examinations, all pathologists' observations, electroencephalographic, electrocardiographic, photomotographic, thermographic, and anthropometric studies.

Part 4. Observations not categorized in *Parts 0-3.* Examples are nurses' notes and observations of other paramedical personnel.

Part 5. Provisional diagnoses, impressions, and other notes by any PMG physician, including radiologists and other consultants, intended as reminders to "rule out" or "consider", but not as firm diagnoses at the time. These impressions are not to be included in insurance reports.

Part 6. Current firm diagnoses made by PMG physicians, including pathologists.

Part 7. Prognoses and estimates of future events, including assessments of rehabilitation potential.

Part 8. Therapeutic procedures, and diagnostic studies entailing drug administration, ordered or performed by physicians, nurses, or other personnel. Examples are drugs or diets prescribed or given, surgical procedures, orthopedic appliances, occupational therapy, physical therapy.

Part 9. All recommendations not therapeutic in themselves and not included in Part 8, such as return appointments, referral to another physician or optometrist, ordering of tests, and physicians' suggestions.

"MEDICAL DATA": DEFINITION, CATALOGING, STORAGE

All "medical data", as defined in the following paragraph, are stored at Level 4 or below.

Definition: Because the PCMR is a variable-length, variable-format record, so that a medical datum cannot be identified merely by fixed field positions within the record, the identification and format of each variable must be stored, as well as the value. Each datum is therefore considered to comprise three parameters: *item identification, value, format.* An *item identification* is a variable such as a test, a procedure, a medical question, etc. An item *value* is the result of the item; it may be a numeric value such as 250, an English language value such as "yes," "hiatus hernia," or "test not done." The item *format* is the field length and type of element in which the value is expressed, such as integer, floating point, characters, text, or other.

Some examples of medical data are shown in Table 2.

Item Catalog. An item catalog, established as a master index to all items, is a direct-access dataset within MFCS. Two of its several hundred pages are shown in Fig. 2. More important than its function as a master index, the item catalog becomes a form for standardization of all input. Before any program can be written to receive data for any medical application via any input medium (punched cards, optical mark read form, magnetic tape, on-line

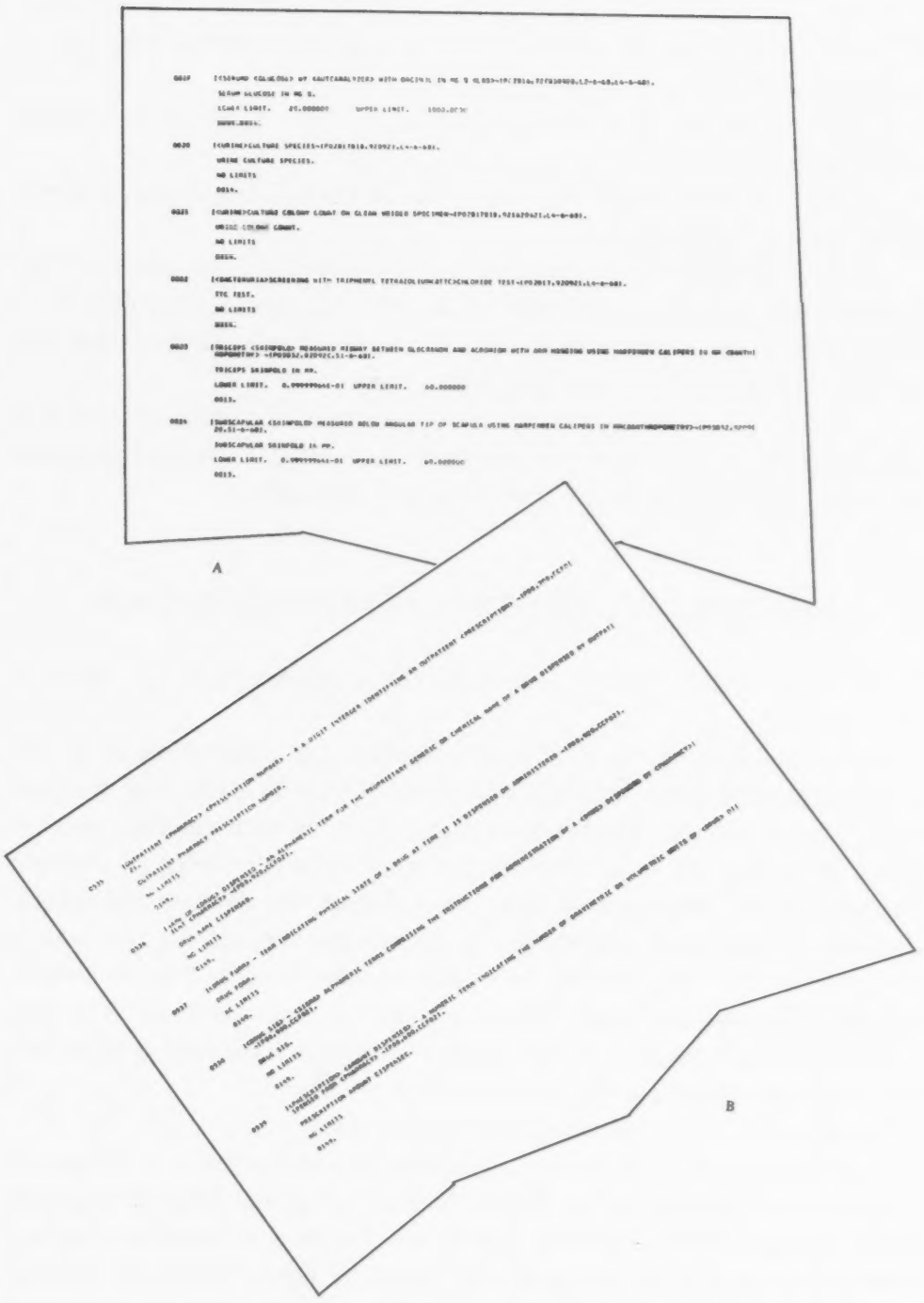


Figure 2A,B. Sample pages from Item Catalog.

Table 2.–Examples of items, format, and value in the PCMR.

Item	Format (Length)	Value
Serum Glucose in mg%	Integer	250
Interval Medical History Question No. 18 (Skin Rash)	English word (1)	Yes
Urine Culture Test	English word (1)	Negative
Diagnosis	English word (2)	Dermatitis Seborrheic
Drug Name	English word (1)	Valisone
Drug Form	English word (1)	Tablets
Prescription Amount Dispensed	Floating Point (1)	15.0

terminal, or other), the input variables must be checked against the current item catalog. Any unlisted item must be defined. The definition includes six sections, exemplified by the definition of "serum glucose" in Fig. 2A:

1. The next available Catalog Item Identifier of Data (CIID) number is assigned (for serum glucose, 001F).
2. The variable is completely defined, including identifying key words with brackets (first line up to the ¬ sign.)
3. The part is identified (P02 for serum glucose), summary bit number shown (B16 for serum glucose), and possible formats that may be used in storing this datum are indicated (for serum glucose, 720830920). These entries comprise the remainder of line 1 after the ¬ sign.
4. A short description, appropriate for printing item identification in medical reports, is entered in Line 2.
5. If the value is quantitative, upper and lower machine (validity) limits are entered in Line 3.
6. Cross-indexing numbers, referring to programs that process this item, are entered in Line 4.

The CIID and format are stored by code number in the PCMR. The data in Table 2 would thus be stored in the PCMR as shown in Table 3. To facilitate

item reviews for standardization or research, an alphabetic key word list is provided. A sample page appears in Fig. 3.

Table 3.–Examples of storage of the items in Table 2, in the PCMR.

Item Identifier (CIID)	Format	Value
001F	720 (1)	250
040E	920 (1)	YES
0022	920 (1)	NEGATIVE
02CC	920 (2)	DERMATITIS SEBORRHEIC
0536	920 (1)	VALISONE
0537	920 (1)	TABLETS
0539	600 (1)	15.0

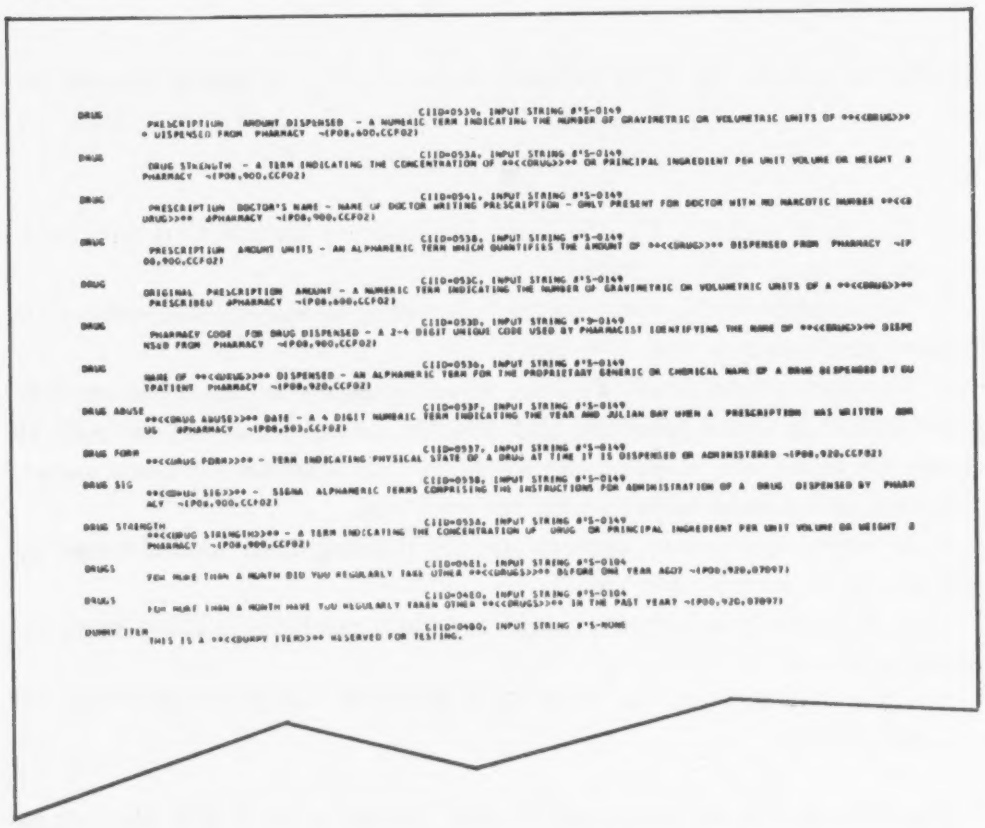

DRUG
CIID=0539, INPUT STRING 0*S-0149
PRESCRIPTION AMOUNT DISPENSED - A NUMERIC TERM INDICATING THE NUMBER OF GRAVIMETRIC OR VOLUMETRIC UNITS OF **<<DRUG>>*
* DISPENSED FROM PHARMACY ~(P08,600,CCF02)
DRUG
CIID=0534, INPUT STRING 0*S-0149
DRUG STRENGTH - A TERM INDICATING THE CONCENTRATION OF **<<DRUG>>** OR PRINCIPAL INGREDIENT PER UNIT VOLUME OR WEIGHT A
PHARMACY ~(P08,900,CCF02)
DRUG
CIID=0541, INPUT STRING 0*S-0149
PRESCRIPTION DOCTOR'S NAME - NAME OF DOCTOR WRITING PRESCRIPTION - ONLY PRESENT FOR DOCTOR WITH NO NARCOTIC NUMBER **<<D
URUG>>** @PHARMACY ~(P08,900,CCF02)
DRUG
CIID=0538, INPUT STRING 0*S-0149
PRESCRIPTION AMOUNT UNITS - AN ALPHAMERIC TERM WHICH QUANTIFIES THE AMOUNT OF **<<DRUG>>** DISPENSED FROM PHARMACY ~(P
08,900,CCF02)
DRUG
CIID=053C, INPUT STRING 0*S-0149
ORIGINAL PRESCRIPTION AMOUNT - A NUMERIC TERM INDICATING THE NUMBER OF GRAVIMETRIC OR VOLUMETRIC UNITS OF A **<<DRUG>>**
PRESCRIBED @PHARMACY ~(P08,600,CCF02)
DRUG
CIID=053D, INPUT STRING 0*S-0149
PHARMACY CODE FOR DRUG DISPENSED - A 2-4 DIGIT UNIQUE CODE USED BY PHARMACIST IDENTIFYING THE NAME OF **<<DRUG>>** DISPE
NSED FROM PHARMACY ~(P08,900,CCF02)
DRUG
CIID=053A, INPUT STRING 0*S-0149
NAME OF **<<DRUG>>** DISPENSED - AN ALPHAMERIC TERM FOR THE PROPRIETARY GENERIC OR CHEMICAL NAME OF A DRUG DISPENSED BY OU
TPATIENT PHARMACY ~(P08,920,CCF02)
DRUG ABUSE
CIID=053F, INPUT STRING 0*S-0149
<<DRUG ABUSE>> DATE - A 4 DIGIT NUMERIC TERM INDICATING THE YEAR AND JULIAN DAY WHEN A PRESCRIPTION WAS WRITTEN @DR
UG @PHARMACY ~(P08,903,CCF02)
DRUG FORM
CIID=0537, INPUT STRING 0*S-0149
<<DRUG FORM>> - TERM INDICATING PHYSICAL STATE OF A DRUG AT TIME IT IS DISPENSED OR ADMINISTERED ~(P08,920,CCF02)
DRUG SIG
CIID=0538, INPUT STRING 0*S-0149
<<DRUG SIG>> - SIGNA ALPHAMERIC TERMS COMPRISING THE INSTRUCTIONS FOR ADMINISTRATION OF A DRUG DISPENSED BY PHAR
ACY ~(P08,900,CCF02)
DRUG STRENGTH
CIID=0534, INPUT STRING 0*S-0149
<<DRUG STRENGTH>> - A TERM INDICATING THE CONCENTRATION OF DRUG OR PRINCIPAL INGREDIENT PER UNIT VOLUME OR WEIGHT A
PHARMACY ~(P08,900,CCF02)
DRUGS
CIID=0481, INPUT STRING 0*S-0104
YOU HAVE TAKEN A MONTH DID YOU REGULARLY TAKE OTHER **<<DRUGS>>** BEFORE ONE YEAR AGO? ~(P00,920,070971)
DRUGS
CIID=0480, INPUT STRING 0*S-0104
FOR MORE THAN A MONTH HAVE YOU REGULARLY TAKEN OTHER **<<DRUGS>>** IN THE PAST YEAR? ~(P00,920,070971)
DUMMY ITEM
CIID=0480, INPUT STRING 0*S-NONE
THIS IS A **<<DUMMY ITEM>>** RESERVED FOR TESTING.

Figure 3. Sample page from alphabetic keyword list.

Storage. Storage of data from the outpatient pharmacies in the Kaiser-Permanente San Francisco facility is exemplified in Fig. 4. Starting June

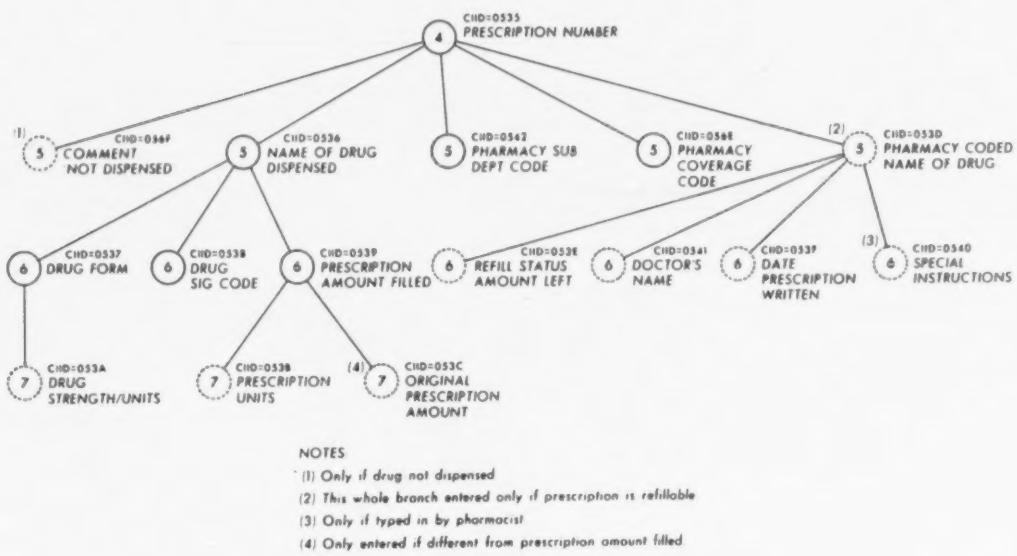


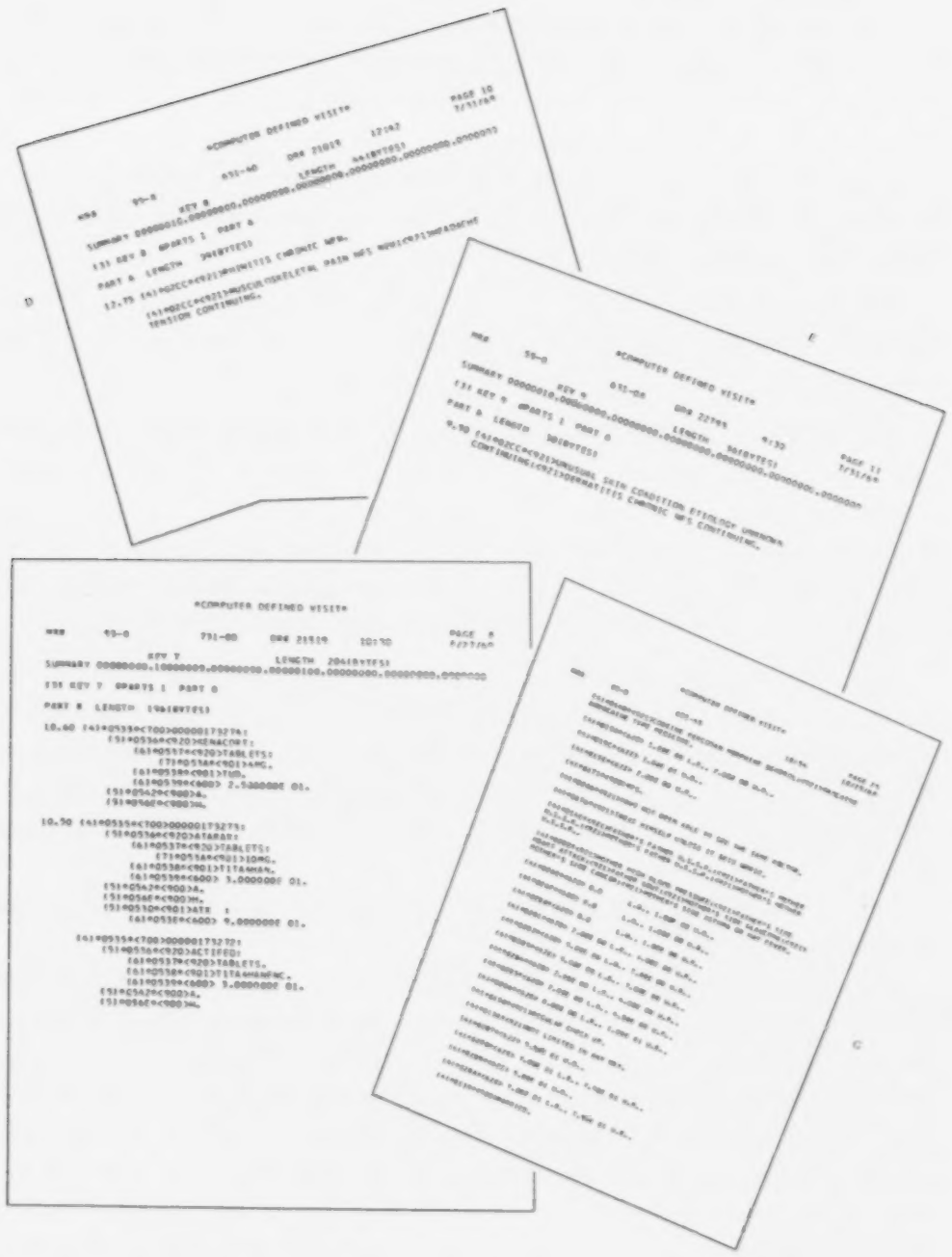
Figure 4. PCMR storage form for outpatient pharmacy.

27, 1969, five on-line typewriter terminals in the three outpatient pharmacies input more than 1000 prescriptions daily. At Level 4 (next below Level 3, Fig. 1), the prescription number is stored. All items relating to any preceding item are stored at subordinate levels (increasing level numbers). The schema in Fig. 4 shows only the CIID's; in an actual record, the format and value for each item would also be stored at each node. Groups of formats, values, and their related CIID's are linked to continue the tree structure below Level 4. Thus, within any one part, level numbers 5 through 11 associated with a CIID imply that the CIID is related to a preceding group. If the level number of a group is N ($N > 4$), it is linked to the first preceding group that has an associated level number N-1. Since several independent Level 4 items within one part are usual for each visit (see Fig. 5D), if within one part level numbers greater than 4 are used, then the succeeding Level 4 group is, by rule, independent of any group that may precede it.

Extracts from a complete printout of a real patient's computer record are shown in Fig. 5. The style of printout was developed to aid the programming staff to check out programs; it is never used to report patient data to a physician.

Figure 5. Extracts from actual Patient Computer Medical Record (PCMR)

A, Medical record index, year index, and computer defined visit index.
B, Identification section. (Values for certain items in Part O relating to personal patient identification have been blocked.)
C, Administrative section.



D,E, Visit to medical clinic: diagnosis data.
F, Visit to pharmacy: drug dispensed data.
G, Visit to multiphasic health testing laboratory: patient medical history data.

In Fig. 5A, the Medical Record Index section includes the patient's medical record number, the summary bits, the length of bytes (8 bit characters) for each section (IS, AS, MDS), the number of YI nodes, and the number of CDV index nodes. The *merge indicator* bits (last line of the MRI) reflect the status of the record. For example, in the event that the direct-access storage facility is not operable, the MFCS establishes, upon receipt of data for a PCMR, a temporary PCMR on an alternate device, and turns on the appropriate merge indicator bit. When the direct-access facility resumes operation, the MFCS merges the two records and turns off the bit.

The Year Index section Fig. 5A contains a count of the number of visit nodes for each year, and the total length in bytes of the data for all visits in each year.

The CDVI section of Fig. 5A shows the CDV index nodes, in reverse chronologic order, and the information stored in each. A "6" in the column headed "SER" (service) means "office visit by appointment"; "7," "office visit, nonappointment." The department codes appearing on this sheet are: 8, dermatology; 40, internal medicine; 45, multiphasic health testing; 80, pharmacy. Time and date are listed in 24-hour, and Julian day notation.

Fig. 5B and 5C illustrate the IS and AS respectively. While the IS and AS do not have a YI or CDVI, the data in IS and AS are stored at Level 4 in order to make these sections compatible with the MDS. For example, as seen in Part 1 of the IS, the year of birth (Item identifier Code *0005*) appears at Level 4, with format < 720 > (integer). All data in IS and AS are also defined as items with formats and values.

Fig. 5D and 5E illustrate storage of diagnosis data from medical and dermatology clinics.

Fig. 5F shows that, at a single outpatient pharmacy visit, the patient had filled three prescriptions written by one physician; a prescription written by a different physician, or purchased by the patient on a different day, would constitute a separate pharmacy visit. For each pharmacy visit, the data for each prescription are stored in groups, each beginning at Level 4; and all three groups of prescription data are in Part 8 of the same visit. Comparison of any one of the three prescriptions in Fig. 5F with the PCMR storage form for outpatient pharmacy visits in Fig. 4 demonstrates PCMR storage of drug data.

Fig. 5G, one of several pages of a multiphasic laboratory visit, is the second page of Part 0 (history). CIID 014E is the grandparents' place of birth; CIID 02BD is family history.

CURRENT STATUS OF COMPUTER MEDICAL RECORDS

The MFCS, using the PCMR strategy described, has been in on-line use since August 1968. At the start, it stored data received from remote telecommunication terminals in two multiphasic health testing laboratories.[12] Since then, other applications have been added such as outpatient pharmacy with on-line typewriters, reporting of outpatient office visit data by means of optical mark read diagnosis forms, and two additional multiphasic laboratories. Further applications, including a hospital visual display terminal system, are in development and will be phased in as they are completed.

SUMMARY

A direct-access generalized computer medical record is structured to store all essential medical data. The basically tree-structured record is partitioned into patients' visits, which are subdivided into parts containing medical history, examination findings, diagnoses, laboratory results, etc. Standardization of variable (item) definitions is discussed and an item catalog is demonstrated.

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THE MEDICAL INFORMATION SYSTEM (MIS) OF 1975

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The question of what a medical information system (MIS) will be in 1975 is, of course, an interesting one. Unfortunately, I have no reason to believe that my crystal ball has a five-year range and I seriously suspect that I am by no means alone in this regard. In view of this, I shall address myself to questions that must be considered if the medical information system of 1975 is to make a meaningful contribution to the delivery of health services as opposed to research. Basic to much of this discussion will be two assumptions, and I call your attention to the differences in the ways that certain terms have been used. The first is that the MIS has as its function the acquisition, organization, storage, retrieval, and communication of those items of information which comprise the medical record as opposed to other data necessary to the functioning of a medical care facility. Thus as I am using the term, MIS is not coextensive with a hospital information system but is, rather, one of the more important components of the larger system. I also assume that we are dealing with the question of an MIS for use in small to medium-sized nonacademic hospitals, and in the ambulatory services related to them, since this is where the vast majority of institutional health care is delivered and, thus, the vast majority of medical records are generated. Out of this latter assumption grow a number of considerations which, if ignored, could lead to the generation of a marvelous research tool without hope of significant impact on the health care system of the country.

Let us begin by considering why it appears desirable to automate medical information. First, it is generally assumed that the quality of medical care would be improved by faster flow of more information within the delivery system, with particular emphasis on the hospital. Although this is undoubtedly true, there are special considerations. As an example, more rapid transmission of requests for laboratory tests is useless without attention to the problem of obtaining specimens and delivering them to the laboratory. If the more rapid

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communication can contribute to a significant decrease in length of stay, the financial benefits to the patient and his insuror are obvious, as are benefits resulting from a decreased pressure for the construction and staffing of new facilities. A further opportunity for cost containment lies in the commonly heard estimate that from one fourth to one third of the total expenditures of a hospital can be attributed to information handling and communication. This figure contains estimates of the fraction of the time of various personnel spent in performing such functions. Decreasing that time fraction could free scarce personnel for the performance of more directly patient-related functions. Realization of these potential benefits might, of course, fail for any one of a number of causes.

Viewed as a service tool, the system will have to be more cost-effective than would be required of a research tool. Otherwise, many of the reasons for its implementation disappear. The statement has been made that, were it not for the invention of the dial telephone, by now most of the population of the country would be needed as telephone operators. It is highly important that the development of information systems have a similar effect rather than merely altering the personnel mix in such a way that the hospital can get along with eight fewer nurses by hiring eight additional persons to operate the information system, assuming similar length of training and salary scales. Obviously, if the system requires more time of medical personnel, any apparent improvement in quality or efficiency is probably illusory.

Other problems arise as one considers the financial aspects of the situation. Although the figure is obviously very "soft", I have been told that if a hospital is built at a cost of $30,000 per bed, in today's money market, the per diem charges for that bed will have to include something between five and ten dollars per patient day for interest alone. This points to the necessity for careful consideration of initial hardware cost, with redundancy minimized insofar as is consistent with reliability; and requires that no features be incorporated into the system because, although not really justified, they are within the state of the art. On this question, as on many others which will be touched on, obviously agonizing trade-offs must be sought between what could be done and what can be afforded.

The various considerations just discussed bear heavily when one looks at the situation from the point of view of containment of the costs of health care and of efficient utilization of manpower. They do not really speak to the question of physician acceptance, which I assume to be conditioned on factors among which expense is not primary. One might say that, in general, the physician's basic requirement is a system that reliably and continuously provides valid

information in a timely way. If a system goes down frequently or unpredictably, or does not run on all shifts, or provides slow response to inquiries, cooperation will quickly vanish. If the svstem is otherwise perfect but provides for data capture that is relatively time-consuming or requires nuisances such as typing, it is unlikely to be accepted and used.

There is also an element of mistrust to be overcome. Several years ago, before the complexity of the handling of information in medicine was properly realized, the prowess of computers for solving all ills of the health care system was considerably oversold. This has led to a reluctance on the part of both physicians and administrators to invest in expensive systems which they believe unlikely to perform the required function in an acceptable way. Without a careful and objective evaluation of any MIS, acceptance of the finest system in the world would be slow. Related to this is my belief that an MIS that is not capable of cohabiting with a management information system has little chance of general deployment. This is because I suspect that, in most hospitals, decisions to make such major investments are made by a board of trustees with heavy business representation and very little professional representation. These persons are aware of the cost effectiveness of automation for accounting and management information, and could be expected to be more receptive to what might be described as a "piggy-back" MIS than to a free-standing MIS.

There is some reason to believe that physicians comprise one of the most conservative groups to be found. As such, they are resistant to changes that do not furnish obvious advantages. If a proposed MIS requires numerous changes in the local, traditional way of keeping records, it will encounter such resistance. This is likely to be true even though the manual system contains many unnecessary accretions which result in needless input time and needless search time to find what are the few grains of wheat, from a professional point of view, in a pile of chaff. Clearly two problems are involved here and it might be wiser to discuss them individually.

The other problem is the question of the content of the record and the purpose of the various items contained therein. I suspect that in general any given item of information is included for one of four reasons. It may be information needed for the care of the patient. It may be information needed for the administration of the hospital or for accounting purposes. It may be information that is required by law but serves no other purpose. A fourth kind of information is that which now serves no purpose whatever, but which has crept into the record system and will remain there, useless, until a penetrating review is made of the reasons for inclusion of each item in the record. I believe that there is a good argument for rationalizing the content and format of the

medical record with automation in mind, but prior to, rather than simultaneously with, the automation. This could conceivably decrease the degree of resistance encountered, by diminishing the rate at which change occurs. In some settings, with small patient loads involved, restructuring without automation could meet the real needs for the foreseeable future. In any event, the evaluation would be improved.

Among the legal requirements that must be considered is authentication of several items of information contained in the record. Although a number of schemes have been proposed or tested for restricting access to the record to those entitled to it, either for input or output purposes, I am not aware of substantial progress towards solution of the problem of identifying the person entering data into the record to the degree of certainty normally required by law. Further, though not insurmountable, problems could arise in a record system shared by several hospitals; and yet other problems could arise when several hospitals in a locality have separate and generally incompatible systems. The advantages of the capability of transferring a patient's record from one hospital to another are obvious, but serious concern about central and transmissible data banks of such personal information as the medical record is inevitable. Clearly, aspects of the problem face us with a morass in which professional, technical, and sociopolitical questions are intermeshed.

In dealing with the development of MIS the exportability of a system to a different institution is important. It could not conceivably be cost effective for each potential using institution to develop a system from "scratch." Differences in local procedures and in local language must be taken into account. The amount of jargon in physicians' writing is probably large enough either to force local modifications of applications programs or to require that systems designers face the resistance to change mentioned earlier. Intimately related to these considerations is the question to what extent any given group of physicians could be expected to accept any given group of multiple-choice answers that would restrict their freedom in writing notes or orders. At the other end of the spectrum of structuring is the processing of plain language with its considerably larger systems requirements. Perhaps these various worries can be summarized by asking how many different medical information systems might be necessary and to what extent we are in danger of encountering prohibitive reprogramming costs in the wide deployment of such systems. I'm not sure that adequate numbers of programmers are readily available.

We have touched previously on a number of questions generally relating to hardware. The exact nature of terminals will greatly influence acceptance of a system by those required to input information. Careful consideration must be

given to the various "trade-offs" involved. The same is true of output devices. How frequently is hard copy desired? With what rapidity? What are the prospects for the commercial availability of printers quiet enough for the ward? It will probably be some time before we shall see any significant efforts by manufacturers towards the development of specialized equipment designed primarily for medical use. The uncertainty of the medical market is legendary among instrument manufacturers. They tend to design equipment for larger and more certain markets, and to assume that other kinds of problems can be dealt with without specialized equipment. Also, any equipment designed and manufactured especially for the medical market is apt to be expensive to a degree that would seriously affect the cost/benefit ratio.

With respect to record storage, assuming that it is necessary or desirable that certain portions of the record be retained more or less permanently, but without the need for rapid access, provision would need to be made for either dumping to tape or storage as hard copy, depending upon the requirements. How shall hard copy be stored without the present problems of the amount of space required and the difficulty of retrieving a particular record? One sometimes hears suggestions of more-or-less indefinite storage on disc, in case rapid retrieval might very occasionally be desired. I would consider this, except for research purposes, an example of highly dubious cost effectiveness which we must avoid in attempting to develop systems of widespread applicability in the real world. The job is difficult, expensive, and time-consuming enough when every effort has been made to make the system cost effective. To what extent are microform techniques an obvious method to consider?

Let us turn briefly, now, to the more general problem of the hospital information system, containing a number of kinds of information in addition to those kinds normally found in the medical record. It can be considered to include all of the potentially automated information sources, data transformation and management requirements, and user information needs in a patient management facility. Since that facility is not a homogeneous activity but, instead, a collage of activities of varying degrees of complexity and varying degrees of interrelationship, the need for automation can be expected to develop in different areas at different times. It is probably unrealistic to speak of a "total hospital information system" if, by that, one means simultaneous automation of all aspects of information flow within the institution. First, there are elements of such a system which are as yet unsolved problems. Then there is the point that an area of activity which has not yet felt an urgent need for increased efficiency will not cooperate fully with a new system. I strongly suspect that any hospital information system must be implemented in a

piecemeal fashion, and that the sequence of implementation of the modules in various activities must be judiciously planned if the result is not to be an expensive catastrophe. Implicit in this viewpoint is the idea that the hospital information system would thus be not a homogeneous information system but a communications network of information subsystems. Also, the over-all problem may present too broad a front for successful attack by a team of manageable size. Therefore it appears that for the foreseeable future we will continue to see research and development teams working on various aspects of an information system, and that at some point in the future a total information system will have been attained. In short, the old Chinese proverb that the longest journey begins with a single step is incomplete. The journey also continues that way.

I have presented enough questions and few enough suggestions of answers to indicate why it is very difficult to guess what the MIS of five years hence will be like. Very difficult problems have been solved and very difficult problems are yet to be faced. In the final analysis we shall undoubtedly encounter the crucial dilemma of allocation of resources. The magnitude of funding required for large-scale deployment of automated information systems is frightening. The magnitude of funding required for research and development in the area is large. I would be less than candid if I did not acknowledge the difficulties arising from the year-to-year uncertainty of the availability of research support, or that the total amount of such support made available up to now has been small when compared with either the difficulty of the problem or the impact of the problem on the cost of health care. But I have heard enough in the last three days to see more cause for optimism than for the pessimism which may seem to characterize my remarks. I am not, in fact, pessimistic; but have attempted to function as a gadfly when faced with the opportunity of talking to a group who have contributed as much to the solution of this set of problems as many of you have.

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